A TEXT-BOOK
ON
CERAMIC CALCULATIONS

W. JACKSON, A.R.C.S.

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WITH EXAMPLES

BY

W. JACKSON, A.R.C.S.

LECTURER IN POTTERY AND PORCELAIN MANUFACTURE FOR
THE STAFFORDSHIRE EDUCATION COMMITTEE AND
THE HANLEY EDUCATION COMMITTEE

LONGMANS, GREEN, AND CO.

39 PATERNOSTER ROW, LONDON

NEW YORK AND BOMBAY

1904

PREFACE

The following pages have been written primarily for the use of the classes in Pottery and Porcelain Manufacture, held under the direction of the Staffordshire Education Committee. Since the recasting of the syllabuses of the City and Guilds of London Institute for this subject a few years ago, when the application of mathematical and chemical methods to the consideration of the problems presented for solution in the course of the manufacture of pottery was first introduced, a collection of methods and examples such as are included in this work has been sorely needed.

The object of the author has not been to write a text-book on pottery manufacture. Descriptions of processes and discussions of the practical requirements of bodies, glazes, etc., are entirely absent, except in so far as they are necessary to an understanding of the arithmetical methods under description. Hence, for example, there is no general dissertation on the subject of fritting, nor on the principles underlying the compounding of fritts. On these and similar points information must be sought in special works dealing with those subjects.

While it is hoped this small work may be welcomed by the students in our technical schools, in so far as they are concerned with pottery (and glass) manufacture, it may prove of some slight value to the general public engaged in these industries.

W. JACKSON.

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December, 1903.

CONTENTS

USEFUL NUMERICAL DATA

CONVERSION of length from English to metric systems, and *vice versâ*—

1 inch	=	0·0254 m. = 25·4 mm.
1 foot	=	0·3048 m.
1 yard	=	0·9144 m.
1 metre	=	39·371 in.
1 millimetre	=	0·03937 in.

As an approximation, near enough for many purposes, it may be taken that 2 in. = 5 cm. = 50 mm.

Conversion of areas—

1 sq. in.	=	6·451 sq. cm.
1 sq. cm.	=	0·155 sq. in.

Conversion of weights—

1 grain	=	0·0648 gram
1 oz. avoir.	=	28·35 grams
1 lb.	=	453·593 grams
1 ton	=	1016·05 kilogs.
1 gram	=	15·432 grains
1 kilog.	=	2·2045 lbs. (= $2\frac{1}{5}$ nearly)
1000 kilos.	=	1 ton nearly

The commercial practice is to consider 1000 kilos. = 1 ton.

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1 lb. per sq. in.	=	70·3 grams per sq. cm.
1 kilog. per sq. cm.	=	14·2 lbs. per sq. in.

Conversion of capacity or volume—

1 c. in. = 16·383 c.c.
1 pint = 568·23 c.c.
1 gallon = 4·546 litres
1 c.c. = 0·061 c. in.
1 litre = 1·76 pint = 0·2201 gallon

A gallon of water weighs 10 lbs.; 1 pint weighs 20 oz. 1 cubic foot of water weighs 62·278 lbs. (= $62\frac{1}{4}$ nearly).

34·683 c. in. = 1 pint
437·5 grains = 1 oz. avoir.
7000 ,, = 1 lb.
5760 ,, = 1 lb. troy

Mohr's Scale of Hardness.

(1) Talc; (2) Gypsum; (3) Calcspar; (4) Fluorspar; (5) Apatite; (6) Orthoclase; (7) Quartz; (8) Topaz; (9) Corundum; (10) Diamond.

LIST OF ELEMENTS AND COMPOUNDS OF IMPORTANCE IN POTTERY MANUFACTURE

Name.	Formula.	Molecular or atomic weight.	Specific gravity.
Aluminium	Al	27·0	2·56–2·67
Alumina	Al_2O_3	102·0	3·75–4
Aluminium sulphate ...	$Al_2(SO_4)_3.18H_2O$	665·0	2·71
Ammonia	NH_3	17·0	—
Ammonia alum ...	$Al_2(SO_4)_3.(NH_4)_2SO_4.24H_2O$	904·0	1·63
Ammonium bichromate	$(NH_4)_2Cr_2O_7$	253·0	2·367
Antimony	Sb	120·0	6·715
Antimony oxide ...	Sb_2O_3	287·0	5·6
Arsenic	As	75·0	4·71–5·73
Arsenic oxide	As_2O_3	198·0	3·7–3·738
Barium	Ba	137·0	—
Barium carbonate (witherite)	$BaCO_3$	197·0	4·275
Barium chloride ...	$BaCl_2$	244·0	3·05
Barium chromate ...	$BaCrO_4$	253·0	3·9
Barium oxide	BaO	153·0	5·4
Barium sulphate ...	$BaSO_4$	233·0	4·48–4·53
Bismuth	Bi	207·5	9·9
Bismuth oxide ...	Bi_2O_3	468·0	8·868
Boron	B	11·0	8·9–9·3
Borax: *see* Sodium biborate			
Boric acid	H_3BO_3	62·0	1·43
Boric oxide	B_2O_3	70·0	1·83
Calcium	Ca	40·0	1·578
Calcium carbonate (carbonate of lime) ...	$CaCO_3$	100·0	2·72–2·9
Calcium chloride (fused)	$CaCl_2$	111·0	2·21
Calcium fluoride ...	CaF_2	78·0	3·15
Calcium oxide (lime)...	CaO	56·0	3·08
Calcium phosphate ...	$Ca_3(PO_4)_2$	310·0	3·18
Calcium sulphate (gypsum)	$CaSO_4.2H_2O$	172·0	2·32

Name.	Formula.	Molecular or atomic weight.	Specific gravity.
Carbon	C	12·0	—
Carbon dioxide ...	CO_2	44·0	—
Carbon monoxide ...	CO	28·0	—
Chlorine	Cl_2	35·4	—
Chrome oxide	Cr_2O_3	153·0	5·21
Chromium	Cr	52·3	2·36
Chromium sulphate ...	$Cr_2(SO_4)_3.18H_2O$	717·7	3·012
Chromium trioxide ...	CrO_3	100·2	2·74
Cobalt	Co	58·6	8·951
Cobalt carbonate ...	$CoCO_3$	118·5	—
Cobaltic chloride ...	Co_2Cl_6	329·4	—
Cobaltous chloride ...	$CoCl_2.6H_2O$	237·1	1·84
Cobalt nitrate	$Co(NO_3)_2.6H_2O$	290·1	1·83
Cobalt oxide (black) ...	Co_2O_3	165·1	5·1
Cobalt oxide (prep.) ...	CoO	74·5	5·68
Cobalt sulphate ...	$CoSO_4.7H_2O$	280·1	1·924
Copper	Cu	63·2	8·85–8·94
Copper chloride ...	$CuCl_2.2H_2O$	170·5	2·47
Copper oxide	CuO	79·5	6·304
Copper sulphate (blue vitriol)	$CuSO_4.5H_2O$	249·5	2·274
Copper sulphide (copper pyrites)	CuS	95·5	3·98
Cuprous chloride ...	Cu_2Cl_2	198·0	—
Cuprous oxide	Cu_2O	143·0	5·8
Ferric oxide (colcothar)	Fe_2O_3	160·0	5·2–5·3
Ferrous oxide	FeO	72·0	—
Ferroso-ferric oxide (magnetic oxide) ...	Fe_3O_4	232·0	5·18
Ferrous sulphate (green vitrol)	$FeSO_4.9H_2O$	562·0	2–2·1
Ferrous carbonate ...	$FeCO_3$	116·0	3·7–3·9
Ferrous sulphide ...	FeS	88·0	4·84
Gold	Au	196·7	19·26–19·55
Gold chloride	$AuCl_3.2H_2O$	339·2	—
Hydrochloric acid ...	HCl	36·4	—
Iridium	Ir	192·5	21·15
Iron	Fe	56·0	7–7·8
Salts of iron: *see* Ferric and Ferrous			
Lead	Pb	206·4	11·25–11·39
Lead carbonate ...	$PbCO_3$	266·0	6·465
Lead carbonate basic (white lead)... ...	$Pb(OH)_2.2PbCO_3$	773·0	—
Lead chloride	$PbCl_2$	277·0	5·802
Lead chromate ...	$PbCrO_4$	323·0	—

Name.	Formula.	Molecular or atomic weight.	Specific gravity.
Lead oxide (litharge)...	PbO	222·4	9·209
Lead, red	Pb_3O_4	685·0	8·62
Lead sulphate ...	$PbSO_4$	302·0	6·2–6·38
Lead sulphide (galena)	PbS	238·4	7·25–7·7
Magnesium	Mg	24·3	1·743
Magnesium carbonate	$MgCO_3$	84·0	2·9–3·1
Magnesium oxide ...	MgO	40·3	3·07–3·65
Manganese	Mn	55·0	7·2
Manganese carbonate	$MnCO_3$	115·0	3·5
Manganese oxide (braunite)	Mn_2O_3	158·0	4·75
Manganous oxide ...	MnO	71·0	5·09
Tri-manganic tetroxide	Mn_3O_4	229·0	4·72–4·85
Manganese dioxide (pyrolusite)	MnO_2	87·0	4·7–5·02
Manganese sulphate ...	$MnSO_4.7H_2O$	277·0	—
Mennige : *see* Lead, red			
Mercury	Hg	200·0	—
Mercurous nitrate ...	$Hg_2(NO_3)_2$	524·0	—
Nickel	Ni	58·8	8·57–8·8
Nickel oxide	NiO	74·8	—
Nickel sulphate ...	$NiSO_4.7H_2O$	280·8	1·931
Nickel sulphate ...	$NiSO_4.6H_2O$	262·8	—
Nitric acid	HNO_3	63·0	—
Oxygen	O	16·0	—
Phosphorus	P	31·0	—
Platinum	Pt	194·34	21·1–21·7
Platinum chloride ...	$PtCl_4.5H_2O$	426·5	—
Potassium	K	39·0	—
Potassium alum ...	$K_2SO_4Al_2(SO_4)_324H_2O$	948·0	1·73
Potassium antimoniate	$KSbO_3$	206·5	—
Potassium bichromate	$K_2Cr_2O_7$	295·0	1·98
Potassium carbonate ...	$K_2CO_3.2H_2O$	174·0	—
Potassium chromate ...	K_2CrO_4	194·5	2·7
Potassium chrome alum	$K_2SO_4.Cr_2(SO_4)_324H_2O$	999·0	1·83
Potassium iron alum ...	$K_2SO_4.Fe_2(SO_4)_324H_2O$	1006·5	—
Potassium ferricyanide	$K_6Fe_2Cy_{12}$	658·0	—
Potassium ferrocyanide	$K_4FeCy_6.3H_2O$	422·0	—
Potassium hydrate ...	KOH	56·0	2·044
Potassium nitrate (saltpetre)	KNO_3	101·0	2·078
Potassium oxide ...	K_2O	94·0	2·56
Potassium permanganate	$KMnO_4$	158·0	2·71
Potassium-platinum chloride	K_2PtCl_6	485·8	—

Name.	Formula.	Molecular or atomic weight.	Specific gravity.
Sodium	Na	23·0	0·973
Sodium bi-borate (borax)	$Na_2B_4O_7.10H_2O$	382·0	1·69
Sodium bicarbonate ...	$NaHCO_3$	84·0	—
Sodium bichromate ...	$Na_2Cr_2O_7.2H_2O$	299·0	—
Sodium carbonate (soda ash)	Na_2CO_3	106·0	—
Sodium carbonate (crystals)	$Na_2CO_3.10H_2O$	286·0	—
Sodium chloride ...	$NaCl$	58·5	2·13
Sodium chromate ...	$Na_2CrO_4.10H_2O$	342·5	—
Sodium hydrate ...	$NaOH$	40·0	2·13
Sodium nitrate ...	$NaNO_3$	85·0	2·26
Sodium oxide	Na_2O	62·0	2·805
Sodium-ammonium phosphate (microcosmic salt)	$NH_4.NaHPO_4.4H_2O$	210·0	—
Sodium silicate (water glass)	$Na_2Si_4O_9$	301·6	—
Sulphur	S	32·0	1·96–2·07
Sulphur dioxide ...	SO_2	64·0	—
Sulphuric acid ...	H_2SO_4	98·0	—
Sulphur trioxide ...	SO_3	80·0	—
Sulphurous acid ...	H_2SO_3	82·0	—
Sulphuretted hydrogen	SH_2	34·0	—
Silica	SiO_2	60·0	2·6–2·2
Silicic acid	H_2SiO_3, etc.	—	—
Silicon	Si	28·0	2·49
Silicon fluoride ...	SiF_4	104·0	—
Tin	Sn	118·0	7·29
Tin oxide	SnO_2	150·0	6·8
Titanium oxide ...	TiO_2	80·0	3·9–4·3
Uranium	U	240·0	18·68
Uranium oxide ...	UO_2	272·0	10·2
Zinc	Zn	65·1	6·86–7·21
Zinc carbonate ...	$ZnCO_3.H_2O$	143·0	4·3–4·5
Zinc oxide	ZnO	81·0	5·61

IMPORTANT MINERALS

Name.	Composition.	Density.	Hardness.
Agate	Cryst. and amorp. silica	2·5–2·8	7
Alabaster	$CaSO_4.2H_2O$	2·4	1·5–2
Alum	$K_2SO_4.Al_2(SO_4)_3.24H_2O$	1·9	2–2·5
Albite	$Na_2O.Al_2O_3.6SiO_2$	2·5–2·64	6–6·5
Amethyst (quartz) ...	SiO_2	2·6	7
Amphibole (hornblende)	$RO.SiO_2(R = Ca, Mg, Fe)$	2·9–3·2	5·5
Anastase	TiO_2	3·8–3·9	5·5–6
Andalusite	$Al_2O_3.SiO_2$	3·2	7·5
Andesine	$(CaNa_2)O.Al_2O_3.4SiO_2$	2·65–2·75	5–6
Anglesite	$PbSO_4$	6·3–6·35	3
Anhydrite	$CaSO_4$	2·98	3–3·5
Anorthite	$CaO.Al_2O_3.2SiO_2$	2·7–2·75	6
Apatite	$3[3CaO.P_2O_5]Ca(ClF)_2$	3·2–3·5	5
Arragonite	$CaCO_3$	2·95	3·5
Aventurine	Quartz	—	—
Azurite	$2CuCO_3.Cu(OH)_2$	3·5–3·8	3·5–4·25
Baryta (heavy spar)	$BaSO_4$	4·4–4·7	3–3·5
Bauxite	$Al_2O_3.2Al_2(OH)_6$	—	—
Biotite (mica) ...	K_2, Fe, Mg silicate	2·7–3·1	2·5–3
Bole	Ferruginous clay	1·6–2·2	—
Boracite	$2(3MgO.4B_2O_3).MgCl_2$	2·9–2·97	6·5–7
Brown iron stone (limonite) ...	$2Fe_2O_3.3H_2O$	3·6–4	5–5·5
Brown coal (lignite)	55–75 per cent. C.	1·2–1·4	—
Brookite	TiO_2	4·12–4·17	5·5–6
Boronatrocalcite ...	$Na_2O.2CaO.6B_2O_3.18H_2O$	1·6–1·8	Soft
Calcite	$CaCO_3$	2·72	3
Cassiterite	SnO_2	6·8–7	6–7
Cerussite	$PbCO_3$	6·4–6·6	3–3·5
Chalcedony	Quartz	—	—
Cryolite	$Al_2F_6.6NaF$	2·9–3	2·5–3
Chile saltpetre ...	$NaNO_3$	2·1	1·5–2
Chlorite	$8MgO.Al_2O_3.5SiO_2.7H_2O$	2·6–2·7	2–3
Cinnabar	HgS	8–8·2	2–2·5
Chrome iron ore ...	$FeCrO_4$	4·3–4·5	5·5

Name.	Composition.	Density.	Hardness.
Cobalt glance ...	$CoAs_2.CoS_2$	6–6·3	5·5
Copper glance ...	Cu_2S	5·5–5·8	2·5–3
Cuprite	Cu_2O	5·7–6	3·5–4
Celestine	$SrSO_4$	3·96	3–3·5
Corundum	Al_2O_3	3·9–4	9
Dolomite	$CaO.MgO.2CO_2$	2·8–2·9	3·5–4
Erythrine (cobalt bloom)	$Co_3As_2O_8.8H_2O$	2·95	1·5–2·5
Felspar (anorthite, albite, andesine, labradonite, microcline, orthoclase, oligoclase)			
Flint...	SiO_2	2·63	7
Fluorspar	CaF_2	3·18	4
Galena	PbS	7·4–7·6	2·5
Gypsum	$CaSO_4.2H_2O$	2·33	1·5–2
Hæmatite	Fe_2O_3	5·19–5·28	5·5–6·5
Halloysite	$Al_2O_3.2SiO_2.4H_2O$	1·9–2·1	1·5–2·5
Hausmannite ...	Mn_3O_4	4·7	5–5·5
Hayesine (borocalcite)	$CaO.B_4O_6.6H_2O$	1·65	1
Heavy spar	$BaSO_4$	4·4–4·7	3–3·5
Hornblende (amphibole)	$(Ca.Mg.Fe)OSiO_2$	3	5·5
Hornstone	SiO_2	—	—
Hyalite (opal) ...	SiO_2 + water	—	—
Hydromagnesite ...	$4MgO.3CO_2.4H_2O$	2·15	2·5
Ilmenite (titaniferous iron ore)	$FeO.TiO_2$	4·5–5	5–6
Jade	$3MgO.CaO.2SiO_2$	2·9–3·1	6·5–7
Jasper (quartz) ...	$SiO_2(Fe_2O_3)$	—	—
Kaolin	$Al_2O_3.2SiO_2.2H_2O$	2·21–2·26	1
Kieselguhr	SiO_2 (amorphous)	—	—
Kupfernickel ...	$NiAs$	7·33–7·6	5–5·5
Labradorite	$(Na_2Ca)O.Al_2O_3.3SiO_2$	2·67–2·76	5–6
Lepidolite (Lithia mica)	$Li_2O.Al_2O_3(F.OH)_2.3SiO_2$	2·84–3	2·5–4
Leucite	$K_2O.Al_2O_3.4SiO_2$	2·45–2·5	5·5–6
Lignite	60–70 per cent. C.; H_2O, ash	1·2–1·3	—
Limonite	$2Fe_2O_3.3H_2O$	3·6–4	5–5·5
Magnesite	$MgCO_3$	2·9–3·1	4–4·5
Magnetite	Fe_3O_4	5–5·2	5·5–6·5
Malachite	$2CuO.CO_2H_2O$	3·9–4	3·5–4
Manganite	$Mn_2O_3.H_2O$	4·2–4·4	4
Marcasite	FeS_2	4·6–4·8	6–6·5
Marble	$CaO.CO_2$	2·6–2·8	3

Name.	Composition.	Density.	Hardness.
Martite	Fe_2O_3	—	—
Meerschaum (talc) ...	$2MgO.3SiO_2$	0·98–1·2	2–3·5
Mispickel	FeS_2 $FeAs_2$	6–6·4	5·5–6
Mennige (red lead)...	Pb_3O_4	7–7·1	2·5–3
Mica (biotite, muscovite, lepidolite, etc.)			
Microcline	$K_2O.Al_2O_3.6SiO_2$	2·54	—
Muscovite	$K_2O.3Al_2O_3.4SiO_2$	2·7–3·1	2–2·5
Nickel (white) ...	$NiAs_2$	6·4–6·7	5·5–6
Oligoclase	$2(Na_2Ca)O.2Al_2O_0.9SiO_2$	2·63–2·73	6
Olivine	$2MgO.SiO_2$	3·1–3·5	6–7
Orthoclase	$K_2O.Al_2O_3.6SiO_2$	2·4–2·7	6–6·5
Pitchblende (uraninite)	U_3O_4	6·4–6·8	5·5
Psilomelane ...	$BaMnO_3.Mn_2O_3.MnO_2$	3·7–4·7	5–6
Pyrites	FeS_2	4·8–5·2	6–6·5
Pyrites (copper) ...	$Cu_2S.Fe_2S_3$	4·1–4·3	3·5–4
Pyrolusite	MnO_2	4·82	2·5–3
Quartz	SiO_2	2·64–2·66	7
Realgar	AsS	2·4	1·5–2
Rock salt	NaCl	2·25	2
Rock crystal (quartz)	SiO_2	—	—
Ruby	Al_2O_3	3·9–4	9
Rutile	TiO_2	4·18–4·2	6–6·5
Salammoniac ...	NH_4Cl	1·52	1·5–2
Saltpetre	KNO_3	1·9–2	2
Sanidene (glassy orthoclase)			
Schorl (tourmaline)			
Soapstone	$3MgO.4SiO_2.H_2O$	2·26	Soft
Serpentine	$3MgO.2SiO_2.2–3H_2O$	2·5–2·6	2·5–4
Siderite	$FeCO_3$	3·8	3·5–4·5
Sillimanite	$Al_2O_3.SiO_2$	3·23	6–7
Smaltite	$CoS_2.CoAs_2$	6	5·5
Sodalite	$3Na_2O.3Al_2O_3.12SiO_2$.-2NaCl	2·3	5·5
Spathic iron ore (siderite)			
Sphene	$CaO.SiO_2.TiO_2$	3·4–3·5	5–5·5
Spinel	$MgO.Al_2O_3$	3·5	8
Steatite	$3MgO.4SiO_2.H_2O$	2·5–2·8	1·5
Talc (steatite)			
Terra Sienna ...	Ferruginous earth with Manganese	—	—
Tetrahedrite (fahlerz)	$4Cu_2S.Sb_2S_3$	4·5–5·1	3–4·5
Tincal (borax) ...	$Na_2B_4O_7.10H_2O$	1·81	2–2·5
Titanite (sphene)			

Name.	Composition.	Density.	Hardness.
Tridymite	SiO_2	2·28–2·3	7
Tourmaline	$(Al, Fe, Mn, Mg)SiO_2.B_2O_3$	2·9–3·3	7–7·5
Umber	Earthy mixture of Fe_2O_3 and manganese oxide	—	—
Wad	Oxide of manganese with cobalt and copper	3–4	1–6
Willemite	$2ZnO.SiO_2$	3·9–4·2	5·5
Witherite	$BaCO_3$	4·3–4·35	3–3·75
Wollastonite ...	$CaOSiO_2$	2·8	4·5–5
Yellow ochre ...	Ferruginous calcareous clay	—	—
Zinc spar (spathic zinc ore)	$ZnCO_3$	4·5	5

A TEXT-BOOK ON
CERAMIC CALCULATIONS

CHAPTER I.

LOSS OF WEIGHT OF POTTERS' MATERIALS ON DRYING AND FIRING—CONTRACTION—POROSITY—SPECIFIC GRAVITY.

WHEN the raw materials used in pottery manufacture enter the works they are usually moist. The amount of moisture present will vary with the nature of the material and the state of the weather, and also in some cases on the scruples of the dealer. The clays will contain more moisture as a rule than ground materials, and of the clays the more plastic will contain more moisture than the less plastic—that is, ball clay will contain more moisture than china clay, for example. In moist, foggy weather the moisture present in materials will be greater than in dry sunny weather, or sharp, windy, frosty weather. It is of importance to know the amount of moisture present in raw materials. Not only is it unbusinesslike to pay a high price for water, under the guise of clay or something else, and also freight and cartage, but in many cases variation in the amount of moisture in raw materials may lead to serious mishaps.

The determination of moisture is simply carried out by heating, say, 100 grams [1] (or grains) of the substance to a temperature not exceeding 120° C., and determining the loss of weight.

The loss of weight on firing may be due to several factors.

(*a*) Loss of moisture such as is not expelled by drying previously.

(*b*) Loss of combined water, or water of crystallization.

(*c*) Loss of organic matter.

(*d*) Loss of carbonic acid gas, sulphuric acid gas, etc.

The extent of these losses can be found by putting the samples through the glost oven, or in some cases the enamel kiln.

The method of calculation is simple rule of three or proportion. The loss is always to be expressed as a percentage of the original material.

Examples—

1. 53 grams ball clay on drying at 120° C. weighed 44 grams. On passing through the glost oven the weight fell to 38 grams. What was the percentage of moisture in the original clay? What was the percentage loss on firing calculated on the original and also on the dried clay?

Ans. 17 per cent., 28·3 per cent., 13·6 per cent.

2. Two ball clays, in other respects of equal quality, contain respectively (after drying at 120° C.) 12 per cent. and 14 per cent. moisture, organic matter, etc., which are lost on firing. If the price of the former is 16*s.* per ton, what would be a fair price for the latter?

Ans. 15*s.* $7\frac{1}{2}$*d.*

[1] Except when stated to the contrary, all measurements of length, volume, and weight are in metric system.

3. The body materials used on a certain works are as follows, and contain the given amounts of moisture, etc. :—

	Loss at 120° C.	Loss on firing after being dried at 120° C.
Ball clay	20 per cent.	14 per cent.
China clay	8 ,,	12 ,,
Flint	5 ,,	2 ,,
Cornish stone	5 ,,	6 ,,

The body used consists of—ball clay, 30; china clay, 30; flint, 25; stone, 15. The pitchers produced per oven are 15 cwt. Calculate the amounts of the various raw materials represented by this loss. Also their prime cost, taking ball clay, 16*s.* per ton; china clay, 25*s.*; flint, 30*s.*; stone, 40*s.*

			s.	*d.*
Ans. Ball clay,	3·8	cwt. =	3	$0\frac{1}{2}$
China ,,	4·47	,, =	5	7
Flint,	4·27	,, =	6	5
Stone,	2·46	,, =	4	11
			19	$11\frac{1}{2}$

4. It is desired to determine the cost of the raw materials in a piece of biscuit ware which weighs 2 lbs. after firing. The composition of the body, the loss on drying and on firing the raw materials, and their price are as follows :—

	Body.	Moisture lost at 120° C.	Loss on heating after drying at 120° C.	Price per ton.
Ball clay ...	20	25	14·5	15*s.*
China clay ...	30	10	12·5	26*s.*
Flint	30	5	3·25	35*s.*
Stone	20	7	5·0	40*s.*

Ans. 7·68*d.*

5. It is found that fresh borax crystals lose on firing through the enamel kiln 47 per cent. of water of crystallization. By a careless storekeeper the stock of borax had been kept near a hot flue, and the crystals had become of a dead white instead of a clear glassy appearance. They now lost on heating in the same way only 39 per cent. water of crystallization. The recipe for the fritt contained 220 lbs. borax. How much must be now used of the borax which has been dried? *Ans.* 191 lbs.

6. Soda ash, if not kept in a dry warm store, absorbs moisture. A stock had been kept in a damp place, and it was found that when heated before the office fire there was a loss of 8 per cent. The fritt for which this material was used contained 175 lbs. of soda ash. How much of the moist soda must be used per charge?

Ans. 190 lbs.

Contraction.—A clay or body contracts during drying on account of loss of water, and during firing partly on account of loss of water, organic matter, etc., and partly by reason of a fusing together of the ingredients. The amount of contraction may be expressed either as linear or cubical contraction.

The linear contraction is easily found by measuring the article when newly made, when dry, and again when fired, or by measuring the distance between two known points, say fine scratches, at these different times. It is important to know the contraction in order to be able to make moulds, dies, etc., of the exact size required.

The cubical contraction of a piece can be best calculated from the linear contraction, for the volumes of similar pieces are as the cubes of corresponding linear dimensions. Hence, if a length l becomes $l - a$,

the linear contraction is a, and the cubical contraction is—

$$l^3 - (l - a)^3 = l^3 - (l^3 - 3l^2a + 3la^2 - a^3)$$
$$= 3l^2a - 3la^2 + a^3$$

The percentage cubical contraction becomes—

$$\frac{3l^2a - 3la^2 + a^3}{l^3} \times 100 = \left(\frac{3a}{l} - \frac{3a^2}{l^2} + \frac{a^3}{l^3}\right)100$$

Now, a^2 and a^3 are small compared with l^2 and l^3, and may often be neglected. **Hence the percentage cubical contraction is nearly** $\frac{3a}{l} \times 100$, **that is, three times the linear contraction.**

7. If a plate, when made, measures $8\frac{1}{4}$ inches in diameter, and when dry $7\frac{3}{4}$ inches, and when fired $7\frac{1}{8}$ inches, calculate contraction from plastic to dry, plastic to biscuit, and dry to biscuit. *Ans.* 6·06, 13·63, 8·06.

8. A body is known to contract 12 per cent. from making to biscuit. What size must be a mould to make an article 12 inches diameter? *Ans.* 13·63 inches.

9. A tile body contracts from the die to biscuit 6 per cent. What must be the diameter of a die to make a 6-inch tile? *Ans.* 6·38 inches.

10. The linear contractions of a series of bodies are 6 per cent., $7\frac{1}{2}$ per cent., 12 per cent., 3 per cent. Calculate their cubical contraction.

Ans. 17 per cent., 21·0 per cent., 31·86 per cent., 8·7 per cent.

Porosity.—Two methods have been given for determining the porosity of fired and unfired clays and bodies. One, the least exact and rational, measures the amount of water absorbed by 100 grams of the substance; that is to say, the volume of the empty

pores which are filled by the absorbed water is compared with the weight of the piece. Evidently porosity should refer to the proportion which the empty spaces bear to the whole volume of the piece; that is, compare volume with volume, and not volume with weight. The error introduced may be very serious, especially if two bodies or clays are being compared as regards their porosity, and whose specific gravities differ considerably. For instance, suppose 100 grams of body A absorb 12 grams water, and its specific gravity is 2·5. Porosity by first method is 12. Body B, with specific gravity 4·0, absorbs 12 grams water per 100 grams weight. Porosity again is 12, though in this case the volume of the piece B is much less than that of A, because the specific gravity is higher. By the second method the results for the porosity are 30 and 48 per cent. respectively; in other words, 100 c.c. of the two bodies would contain respectively 30 and 48 c.c. empty spaces.

The method is as follows:—

(*a*) For fired pieces. Weigh the dry piece. Then soak it in water, leaving one edge exposed, for 12 hours, or until it is saturated with water. Weigh again. The increase in weight is the amount of water absorbed; if in grams, it is also the volume, in cubic centimetres, of the water absorbed—that is, the volume of the pores. Now suspend the soaked piece from the arm of the balance and weigh again in water completely immersed. The apparent loss of weight is the weight of the displaced water, and if in grams it is also the volume, in cubic centimetres, of water displaced by the piece, and is thus the volume of the piece. Hence we know the volume of the piece and the volume of the empty spaces, both in cubic centimetres, and from these the porosity can

be determined. Expressed as an equation, the rule becomes—

$$\text{Porosity} = \frac{\text{wt. when soaked} - \text{wt. dry}}{\text{loss of wt. when suspended in water}} \times 100$$

(*b*) For unfired clays and bodies at any stage of dryness. It is evidently impossible to use water for filling the pores. Some other liquid must be used which does not soften the clay. Such a one is paraffin. Using paraffin, we proceed just as before, and weigh the piece before soaking, then soaked with paraffin, and finally immersed in paraffin. Now, the volume of the pores in cubic centimetres is not equal to the weight in grams of the paraffin absorbed, for paraffin is lighter than water, and therefore, weight for weight, more bulky. To get the volume of paraffin absorbed, we must divide the weight absorbed by its specific gravity. Similarly, to get the volume of the piece, we must divide its apparent loss of weight when suspended in paraffin by the specific gravity of the paraffin. Then we get the following rule:—

$$\text{Porosity} = \frac{(\text{wt. soaked} - \text{wt. dry}) \div \text{sp. gr. of paraffin}}{\text{loss of wt. when suspended in paraffin} \div \text{sp. gr. of paraffin}} \times 100$$

Or again, simply—

$$\text{Porosity} = \frac{\text{increase of wt. when soaked in paraffin}}{\text{loss of wt. when suspended in paraffin}} \times 100$$

Exactly the same rule applies to both cases.

11. A piece of earthenware weighs dry 95 grams. When soaked in water it weighs 130 grams. It is sus-

pended in water, and now weighs 80 grams. Find its porosity by both systems of calculation.

Ans. 36·8 per cent., 70 per cent.

12. Determine the following porosities :—

	A.	B.	C, in paraffin. Sp. gr. = 0·8.	D.	E.
Weight dry	279	83	76	130	23
„ soaked	310	90	81	135	40
„ suspended ...	210	49	56	90	20

Ans. 31 per cent., 17 per cent., 20 per cent., 11 per cent., 85 per cent.

13. Calculate by both methods the porosity of each of the bodies A, B from given particulars :—

	Specific gravity.	Weight dry.	Weight soaked.	Weight suspended.
A	1·7	150	200	110
B	3·5	275	325	246·4

Ans. A, 33 per cent., 55·5 per cent.
B, 18·0 per cent., 63·6 per cent.

Specific Gravity.—By the term "specific gravity" is meant the weight of any volume of a substance compared with the weight of an equal volume of water. The methods for determining specific gravity vary according as the substance is a liquid or a solid, and also according to its state of aggregation.

(*a*) *Liquids.*—Weigh a certain volume of water, and then weigh the same volume of the liquid to be examined. Divide the latter weight by the former. The quotient is the specific gravity of the liquid.

This method applies to slips of all kinds as well

as to proper liquids. The method used on works is really this method. The weight in ounces of a pint of the slip is found, and the density is expressed by this number. Seeing that a pint of water weighs 20 oz., the specific gravity of a slip is its weight in ounces per pint divided by 20. Similarly, the weight per pint of a slip of any given specific gravity is obtained by multiplying the specific gravity by 20.

Thus—

$$\text{Sp. gr.} \times 20 = \text{wt. in ounces per pint}$$

$$\left.\begin{array}{r}\text{and wt. in ounces}\\ \text{per pint} \div 20\end{array}\right\} = \text{sp. gr.}$$

(*b*) *Solids, when powdered.*—A bottle or other vessel which will hold a known quantity of water is used. Into this bottle is introduced a known weight of the powder. The bottle is now filled up exactly with water, and the weight of water used is found. This can be done by weighing the bottle before and after adding the water. The difference in the weight of water needed to fill the bottle when empty and when containing the powder is evidently the weight of water equal in bulk to the solid. Hence divide the weight of the solid by this difference; the quotient is the specific gravity. Thus—

$$\left.\begin{array}{l}\text{Weight of solid} \div \text{(weight of water to fill}\\ \quad\text{empty bottle less weight of water to}\\ \quad\text{fill bottle containing the solid)}\end{array}\right\} = \text{sp. gr.}$$

Solids, when in the lump.—Weigh the piece of material in the ordinary way. Then suspend from the arm of the balance so that the piece is immersed in water contained in a vessel supported above the balance

pan. Determine the apparent weight of the substance thus suspended. The specific gravity is found by dividing its ordinary weight by its apparent loss of weight when suspended in water. Thus—

$$\frac{\text{ordinary weight in air}}{\text{ordinary weight in air} - \text{weight in water}} = \text{sp. gr.}$$

This method can only be adopted as described above for materials which are not porous. For porous materials it is necessary to first get rid of porosity, either by soaking in water until saturated before finding the weight when suspended in water, or by applying a thin coating of fat—say lard—to the surface of the piece. The specific gravity of a substance which is porous may refer to the whole piece—including pores—or it may refer simply to the solid part of the piece. It is the specific gravity of the whole which is given by the above method.

To find the specific gravity of the solid only, we proceed as follows: find the ordinary weight of the piece. Soak in water and find the weight of water absorbed in grams, and thus the volume in cubic centimetres of the pores. Weigh now suspended in water; the loss of weight in grams is equal to the volume of the whole piece—pores and all—in cubic centimetres. Thus the volume of solid is the difference of these two volumes. Then divide dry weight by this volume. Thus—

$$\left.\begin{array}{r} \text{Weight dry} = 24 \text{ grams} \\ \text{weight soaked} = 30 \quad ,, \end{array}\right\} 6 = \text{pores in c.c.}$$

$$\left.\begin{array}{r} \text{weight soaked} = 30 \quad ,, \\ \left.\begin{array}{r}\text{weight suspended} \\ \text{in water}\end{array}\right\} = 20 \quad ,, \end{array}\right\} 10 = \left\{\begin{array}{l} \text{apparent loss of} \\ \text{weight} = \text{volume} \\ \text{of piece in c.c.} \end{array}\right.$$

Then—

$$10 - 6 = 4 = \text{volume of solid}$$
$$\text{and } 24 \div 4 = \mathbf{6}, \text{ specific gravity of the solid}$$

The specific gravity of the whole piece is—

$$24 \div 10 = \mathbf{2 \cdot 4}$$

To find the specific gravity of clay, the material must be powdered, and the method for powders must then be followed. If it is desired to find the specific gravity of a porous piece of unfired clay, the method described above for a porous substance must be used, but the liquid for soaking, etc., must be paraffin. Then, as previously pointed out, the volume of the pores and of the piece are obtained by dividing the numbers obtained, for the paraffin absorbed, and the apparent loss of weight in paraffin, by the specific gravity of paraffin, which would need to be determined as well.

14. Find the specific gravities of the slips having the following ounce weights : 32 oz., 30 oz., 26 oz., 24 oz.
Ans. 1·6, 1·5, 1·3, 1·2.

15. Find the weight to the pint in ounces of slips having specific gravities as follows : 1·8, 1·63, 1·25, 1·4.
Ans. 36 oz., 32·6 oz., 25 oz., 28 oz.

16. 14 grams of ground (dry) flint are placed in a bottle, which will hold 100 c.c. of water. It then requires 94 grams of water to fill the bottle. What is the specific gravity of the flint? *Ans.* 2·33.

17. A bottle which holds 100 c.c. water, when filled with hydrochloric acid used in making flow powder, weighs 118 grams more than when empty. What is the specific gravity of the acid? *Ans.* 1·18.

18. A piece of biscuit ware weighed when dry 134 grams. Soaked in water it absorbed 16 grams. When

suspended in water its weight was 75 grams. Find (*a*) porosity, (*b*) specific gravity of the whole, (*c*) specific gravity of the solid. *Ans.* 21·3, 1·78, 2·27.

19. From following data calculate porosity, specific gravity of whole, and of solid only of the following pieces:—

	Weight dry.	Weight soaked in water.	Weight suspended in water.
	grms.	grms.	grms.
A	240	260	160
B	158	180	92
C	32	50	24
D	192	210	115
E	78	80	54
F	96	101	71

Ans. A, 20, 2·4, 3.
B, 25, 1·8, 2·4.
C, 69·2, 1·23, 4.
D, 19, 2·02, 2·5.
E, 7·7, 3, 3·25.
F, 16·66, 3·2, 3·84.

20. Calculate the data in question 18, supposing paraffin specific gravity 0·82 were used instead of water.

Ans. A, 20, 2·9, 3·65.
B, 25, 2·2, 2·9.
C, 69·2, 1·5, 4·87.
D, 19, 2·46, 3·05.
E, 7·7, 3·65, 3·96.
F, 16·66, 3·9, 4·68.

21. Flint expands when calcined. If flint, on being put through the kiln, falls in specific gravity from 2·6 to 2·48, what will be its increase in volume per cent.?

Ans. 100 volumes of flint expand to 105, therefore expansion = 5 per cent.

CHAPTER II.

THE RELATIONSHIP BETWEEN SPECIFIC GRAVITY, DRY CONTENTS, AND SLOP WEIGHTS OF SLIPS, ETC.

It is often necessary from a "wet" recipe—that is, a recipe for a body in which the ingredients are measured and mixed in the form of slips—to obtain the corresponding "dry" recipe, and *vice versâ.* It may be advisable at times to add body stains and colouring oxides as slips instead of as dry powders, and to be able to calculate the amounts of the dry materials which are being used. In fact, the principles which will be explained in this chapter are of very general and wide application.

1. To determine the dry weight in ounces of a pint of any slip of a given weight to the pint (in ounces) when the specific gravity of the dry material is known. The rule is as follows:—

The dry contents of a pint of slip is equal to the excess of the pint weight over 20 oz. multiplied by the specific gravity of the dry material, and divided by the specific gravity less 1, or, expressed algebraically—

$$W = (P - 20)\frac{G}{G - 1}$$

where W = the dry contents of a pint of slip,
P = weight to the pint in ounces,
G = specific gravity of the dry substance.

2. Conversely, the weight in ounces of a pint of slip having a given dry contents will be obtained as follows: The weight to the pint is equal to 20 plus the dry contents multiplied by the specific gravity less 1, and divided by the specific gravity of the dry material; or, expressed algebraically—

$$P = 20 + \left(W \times \frac{G - 1}{G} \right)$$

where W, P, and G have the same meaning as before.

Example.—The weight of a ball clay slip is 24 oz. per pint. The specific gravity of the dry clay is 2·6. Find the weight of dry clay in a pint of slip.

$$W = (24 - 20) \times \frac{2{\cdot}6}{2{\cdot}6 - 1}$$

$$= 4 \times \frac{2{\cdot}6}{1{\cdot}6} = \frac{10{\cdot}4}{1{\cdot}6} = \mathbf{6{\cdot}5} \text{ oz.}$$

Example.—Find what will have to be the weight to the pint of a slip of ferric oxide, so that it shall contain 10 oz. of oxide per pint; the specific gravity of ferric oxide being 5·22.

$$P = 20 + \left(10 \times \frac{5{\cdot}22 - 1}{5{\cdot}22} \right)$$

$$= 20 + \frac{42{\cdot}2}{5{\cdot}22} = 20 + 8{\cdot}08$$

$$= \mathbf{28{\cdot}08} \text{ oz. per pint}$$

22. Find the dry contents of a pint of the following slips:—

A, Flint at	32 oz. to pint,	sp. gr. 2·3	*Ans.*	$21\frac{3}{13}$.
B, Cornish stone at	31 ,,	,, 2·4	,,	$18\frac{6}{7}$.
C, China clay at	26 ,,	,, 2·6	,,	$9\frac{3}{4}$.
D, Ball clay at	24 ,,	,, 2·5	,,	$6\frac{2}{3}$.
E, Body stain at	26 ,,	,, 3·5	,,	$8\frac{2}{5}$.
F, Glaze at	28 ,,	,, 4·1	,,	$10\frac{18}{31}$.
G, Cobalt oxide at	30 ,,	,, 5·6	,,	$12\frac{4}{23}$.

23. It is desired to make a series of slips of potters' materials to contain uniformly 10 oz. per pint. Calculate the weights per pint for each of the materials in question 22, assuming the specific gravities to be the same as stated.

Ans. $25\frac{15}{23}$, $25\frac{5}{6}$, $26\frac{2}{13}$, 26, $27\frac{1}{7}$, $27\frac{23}{41}$, $28\frac{3}{14}$.

Considering the formula given for calculating the dry contents of a slip from its weight per pint, and the specific gravity of the dry substance, it will be seen that, for any one material, the dry contents will be proportional to the excess of the pint weight in ounces over 20. For example, take flint with a specific gravity 2·3. The dry contents of a pint of the flint slip is equal to the pint weight less 20 multiplied by $\frac{2\cdot3}{1\cdot3}$. In every case the multiplier $\frac{2\cdot3}{1\cdot3}$ is the same; therefore as regards proportion this factor may be disregarded. Expressed algebraically, we have the following:—

$$W = (P - 20) \times \frac{2\cdot3}{1\cdot3} \text{ in every case}$$

Hence, for instance, the dry contents of slips of flint of 28 and 32 oz. weight to the pint are as 8 : 12. Not only is this true of flint, but of all other substances having the same specific gravity as flint. Therefore, if clays, Cornish stone, felspar, etc., have the same specific gravity as flint, the dry contents of their slips are simply proportional to their excesses over 20 oz. in the weight of the pint. Fortunately, for all but the most exacting purposes, it may be assumed that these

materials have about the same specific gravity. Hence we have the fact that the dry contents of equal quantities of ball clay slip at 24, china clay slip at 26, cornish stone slip at 32, and flint slip at 32, are in the proportion $(24 - 20) : (26 - 20) : (32 - 20) : (32 - 20)$,

$$\text{or as } 4 : 6 : 12 : 12$$
$$\text{or more simply, } 1 : 1\tfrac{1}{2} : 3 : 3$$

Hence a rule which is approximately correct for transferring at once from a wet to a dry recipe: "Take the inches of ball clay as parts by weight dry, take $1\frac{1}{2}$ times the inches of china clay in parts by weight dry, and 3 times the inches of stone and flint." *This, of course, refers only to the above standard weights,* viz. 24, 26, 32, 32 oz. to pint.

Thus a recipe—

5	inches	ball clay	at 24
6	,,	china clay	,, 26
4	,,	stone	,, 32
3	,,	flint	,, 32

becomes as a dry recipe—

	5	parts	dry	ball clay
$6 \times 1\frac{1}{2} =$	9	,,	,,	china clay
$4 \times 3 =$	12	,,	,,	stone
$3 \times 3 =$	9	,,	,,	flint

In this example the proportions of the materials are unaltered, but the total weight of the mixing will, of course, not be the same as that of the wet mixing. It must also be remembered that the rule only applies on the assumption that the specific gravities of the materials are the same.

Examples—

24. Using the above rule, transform the following wet into dry recipes :—

	A.	B.	C.	D.	E.
Ball clay at 24	6	9	5	8	10
China clay at 26	4	8	6	3	5
Stone at 32	3	5	2	2	5
Flint at 32	4	7	3	4	4
Ans.—					
Ball clay	6	9	5	8	10
China clay	6	12	9	$4\frac{1}{2}$	$7\frac{1}{2}$
Stone	9	15	6	6	15
Flint	12	21	9	12	12

25. Using the converse of the rule just described, transform the following from dry to wet recipes. The slips to be taken of the standard weights just mentioned :—

	A.	B.	C.	D.	E.
Ball clay	30	40	25	60	50
China clay	40	20	30	10	15
Stone	10	10	20	5	15
Flint	20	30	25	25	20
Ans.—					
Ball clay	30	40	25	60	50
China clay	$26\frac{2}{3}$	$13\frac{1}{3}$	20	$6\frac{2}{3}$	10
Stone	$3\frac{1}{3}$	$3\frac{1}{3}$	$6\frac{2}{3}$	$1\frac{2}{3}$	5
Flint	$6\frac{2}{3}$	10	$8\frac{1}{3}$	$8\frac{1}{3}$	$6\frac{2}{3}$

The principles explained above have been utilized by Mr. W. J. Furnival, of Stone, in the compilation of "The Slop Flint and Stone Calculator," a set of tables which at once gives the quantities, in inches, of slips of different weights which contain the same dry contents.

It is evident that if a slip is above or below the standard weight used in the recipe, the quantity of slip

used must be either diminished or increased. The extent of the required alteration is seen from the statement that the dry contents of a slip are proportional to the excess of the pint weight over 20 oz. Hence, suppose flint slip, instead of being 32 oz., were 31 only; the dry flint present in the volume of slip used will only be $\frac{11}{12}$ of the amount desired. Hence more slip must be used in the proportion of 12 : 11. *Hence the rule*, that the inches of slip to be used must be multiplied by the excess of the standard pint weight over 20, and divided by the actual excess of the weight per pint over 20, in cases where the slip when used is not of the exact weight required by recipe. Thus a table could be made up somewhat like the opposite, which is for a wet recipe.

Using such a table as the above, a wet recipe can be mixed even though the slips be not brought to the standard weight. On a piece of card can be written the recipe for a pottery body arranged in the above fashion, and a great deal of trouble would be saved the slip-maker, and at the same time more certainty would be obtained in the results. Instead of laboriously endeavouring to bring the slips to the exact weight, it would only be necessary to get them within, say, an ounce of the standard; then, by reference to the card, the inches of slip corresponding to the particular weight would be at once read off. Thus, if the weights of the slips when the recipe was mixed were—

Ball clay, $24\frac{1}{2}$	Stone, $32\frac{1}{4}$
China clay, $25\frac{1}{4}$	Flint, 31

the above recipe would become—

Ball clay, 7·1 inches	Stone, 2·7 inches
China clay, 5·7 „	Flint, 4·35 „

Body Recipe.

8 inches ball clay at 24 oz. 3 inches stone at 31 oz.
5 „ china clay „ 26 „ 4 „ flint „ 32 „

Ball Clay.

22½ 12·8	22¾ 11·6	23 10·7	23¼ 9·8	23½ 9·1	23¾ 8·5	24 oz. 8 inches.	24¼ 7·5	24½ 7·1	24¾ 6·7	25 6·4	25¼ 6·1	25½ 5·8	25¾ 5·5	26 5·3

China Clay.

24½ 6·6	24¾ 6·3	25 6	25¼ 5·7	25½ 5·5	25¾ 5·2	26 oz. 5 inches.	26¼ 4·8	26½ 4·6	26¾ 4·5	27 4·3	27¼ 4·1	27½ 4	27¾ 3·9	28 3·75

Stone.

29½ 3·5	29¾ 3·4	30 3·3	30¼ 3·2	30½ 3·15	30¾ 3·1	31 oz. 3 inches.	31¼ 2·9	31½ 2·85	31¾ 2·8	32 2·7	32¼ 2·7	32½ 2·65	32¾ 2·6	33 2·55

Flint.

30½ 4·55	30¾ 4·45	31 4·35	31¼ 4·25	31½ 4·15	31¾ 4·05	32 oz. 4 inches.	32¼ 3·9	32½ 3·85	32¾ 3·75	33 3·70	33¼ 3·6	33½ 3·55	33¾ 3·5	34 3·45

26. Calculate a slip-maker's card for the following wet recipe, to nearest convenient fraction :—

Ball clay	... ...	16 inches at	24
China clay	... ...	12 ,,	26
Stone	... ...	8 ,,	31
Flint	... ...	10 ,,	32

Ans.—

Ball clay ...	22 32	$22\frac{1}{4}$ 28·7	$22\frac{1}{2}$ 25·5	$22\frac{3}{4}$ 23·3	23 21·2	$23\frac{1}{4}$ 19·7	$23\frac{1}{2}$ 18·2	$23\frac{3}{4}$ 17·1	24 oz. 16 inches.	$24\frac{1}{4}$ 15·1	$24\frac{1}{2}$ 14·2	$24\frac{3}{4}$ 13·5	25 12·7	$25\frac{1}{4}$ 12·2	$25\frac{1}{2}$ 11·7	$25\frac{3}{4}$ 11·2	26 10·6
China clay ...	24 18	$24\frac{1}{4}$ 17	$24\frac{1}{2}$ 16	$24\frac{3}{4}$ 15·2	25 14·5	$25\frac{1}{4}$ 13·8	$25\frac{1}{2}$ 13·1	$25\frac{3}{4}$ 12·6	26 oz. 12 inches.	$26\frac{1}{4}$ 11·5	$26\frac{1}{2}$ 11	$26\frac{3}{4}$ 10·6	27 10·2	$27\frac{1}{4}$ 9·8	$27\frac{1}{2}$ 9·5	$27\frac{3}{4}$ 9·2	28 9
Stone ...	29 9·7	$29\frac{1}{4}$ 9·5	$29\frac{1}{2}$ 9·2	$29\frac{3}{4}$ 9	30 8·8	$30\frac{1}{4}$ 8·6	$30\frac{1}{2}$ 8·4	$30\frac{3}{4}$ 8·2	31 oz. 8 inches.	$31\frac{1}{4}$ 7·8	$31\frac{1}{2}$ 7·6	$31\frac{3}{4}$ 7·5	32 7·4	$32\frac{1}{4}$ 7·2	$32\frac{1}{2}$ 7	$32\frac{3}{4}$ 6·9	33 6·7
Flint ...	30 12	$30\frac{1}{4}$ 11·7	$30\frac{1}{2}$ 11·5	$30\frac{3}{4}$ 11·2	31 10·9	$31\frac{1}{4}$ 10·7	$31\frac{1}{2}$ 10·5	$31\frac{3}{4}$ 10·2	32 oz. 10 inches.	$32\frac{1}{4}$ 9·8	$32\frac{1}{2}$ 9·6	$32\frac{3}{4}$ 9·4	33 9·2	$33\frac{1}{4}$ 9·1	$33\frac{1}{2}$ 8·9	$33\frac{3}{4}$ 8·7	34 8·5

27. A mill delivered 586 pecks of flint at $31\frac{1}{2}$ oz. to a factory. What would be the equivalent amount of a 32-oz. flint slop? *Ans.* $561\frac{7}{12}$.

CHAPTER III.

ON THE FINENESS OF GROUND MATERIALS.

THE influence of the fineness of grinding on the properties of potters' materials cannot be doubted, and it is therefore of importance to be able to compare these ground materials in that respect. The usual method of passing the powders, in suspension in water or dry, through various sizes of lawns is not sufficient. Such a method gives information as to how coarse the material is not, but does not say how fine it is. In fact, the most important variations of fineness are beyond the powers of detection of the finest sieves. The method of elutriation by a stream of water is the only sufficient means at our disposal for this purpose.

The results of elutriation are, however, not readily understood even by those familiar with the method. It is difficult, or almost impossible, to express a decided opinion, by inspection of the results of elutriation, as to the relative fineness of many samples of ground material. The method of comparison by what I have named the "surface factor" enables a judgment to be immediately formed by simple inspection. It depends on the fact that the finer a material is divided, the greater is the total surface of its particles per unit mass, and if the shapes of the particles are taken to

approximate, in the mean, to spheres, the surface varies inversely as the mean diameter of the particles.*

Now, the average diameter of the four fractions usually obtained by elutriation are: 0·005, 0·0175, 0·0325, 0·185 mm. respectively, and the surfaces of equal masses of each fraction will be in the proportion—

$$\frac{1}{50} : \frac{1}{175} : \frac{1}{325} : \frac{1}{1850}$$

or—

$$3367 : 962 : 518 : 91$$

Hence, to get the surface factor of an elutriated sample of ground material, proceed as follows.

Multiply the fraction whose extreme diameters are—

mm.		mm.		
0	–	0·010	by	3367
0·010	–	0·025	„	962
0·025	–	0·040	„	518
0·040	–	0·33	„	91

Add all the products together, and omit the last two figures.

The number obtained—"the surface factor"—indicates by its dimensions the fineness of the material.

* *Proof.*—Let d_1, d_2 be diameters of two spherical particles. Their volumes will be $\frac{\pi d_1^3}{6}$ and $\frac{\pi d_2^3}{6}$ respectively. If their sp. gr. = G, their mass is $G\frac{\pi d_1^3}{6}$ and $G\frac{\pi d_2^3}{6}$, and in unit mass there will be $\frac{6}{G\pi d_1^3}$ and $\frac{6}{G\pi d_2^3}$ particles respectively. The surface of the particles is πd_1^2 and πd_2^2 respectively. Hence total surface of unit mass is $\frac{6}{Gd_1}$ and $\frac{6}{Gd_2}$ respectively, or the surfaces are as $\frac{1}{d_1} : \frac{1}{d_2}$.

Examples.—Which of the samples A, B is the finer?

Diameter of particle.	A.	B.
0 – 0·010	33 per cent.	37·8 per cent.
0·010 – 0·025	30 "	39·0 "
0·025 – 0·040	16 "	16·0 "
0·040 – 0·33	21 "	7·2 "

Surface factor.

A.	B.
33 × 3367 = 111111	37·8 × 3367 = 127272
30 × 962 = 28860	39 × 962 = 37518
16 × 518 = 8288	16 × 518 = 8288
21 × 91 = 1911	7·2 × 91 = 655
1501$\cancel{70}$	1737$\cancel{33}$

Ans. B.

28. Calculate the surface factors of the following samples, which on elutriation gave these results:—

Diameter in mm.	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.
0 – 0·010	44·2	52·2	63·8	9·4	22·2	55·6	38·0	60·2	45·4	36·8	45·4	44·8
0·010 – 0·025	21·0	30·5	19·9	40·6	40·0	10·4	23·2	16·8	24·0	33·4	30·0	21·0
0·025 – 0·040	8·4	7·7	8·5	27·5	18·6	12·0	22·4	11·0	9·4	16·4	10·0	5·0
0·040 – 0·33	26·4	9·6	8·0	22·5	19·2	22·0	16·4	12·0	11·2	13·4	14·6	29·2
Ans.— Surface factors ...	1759	2100	2391	870	1245	2054	1634	2265	1819	1658	1882	1765

CHAPTER IV.

TO CALCULATE THE FORMULA OF A COMPOUND FROM ITS PERCENTAGE COMPOSITION.

In dealing with pottery bodies and glazes, it is advisable in many cases to express their composition as a chemical formula as well as in the form of a percentage. When thus expressed, the relationship existing between their different parts, *e.g.* acids and bases, can be more readily perceived. Deductions as to their character can be more readily drawn; and in cases of faulty constitution, the error can be more easily detected and remedied.

It must, however, always be borne in mind that the full meaning attached to such a formula as H_2SO_4, for sulphuric acid, cannot be read into a glaze or body formula. There is, in the latter cases, no intention to convey the idea that the formulæ represent well-defined chemical compounds. The only reason the formulæ are used is, that they show the proportions existing between the molecular quantities of the several oxides present in these heterogeneous mixtures.

Taking as first examples pure chemical compounds, the method of calculation is as follows:—

(*a*) *Divide the percentage of each oxide present by its molecular weight (or, if the substance is an element, by its atomic weight).*

The quotients obtained represent the molecular or atomic parts of each oxide or element present in 100 parts by weight of the compound or mixture.

Thus, taking the percentage composition of lead carbonate as 83·6 per cent. lead oxide and 16·4 per cent. carbon dioxide, divide as follows:—

$$83{\cdot}6 \div 222{\cdot}4 = 0{\cdot}3759 \text{ molecular parts}$$
$$16{\cdot}4 \div 44 \quad = 0{\cdot}3727 \quad \text{,,} \qquad \text{,,}$$

(*b*) *Divide the quotients obtained in* (*a*) *by some such number that they become as far as possible whole numbers.*

Thus, in the example, dividing both quotients by either of them gives results approximating very closely to unity for both oxides—

$$0{\cdot}3759 \div 0{\cdot}3727 = 1{\cdot}008$$

Hence the molecular proportions of lead oxide and carbon dioxide in lead carbonate, when both are expressed as the least whole numbers, are both units, or, in other words, the compound may be expressed by the formula $PbO.CO_2$.

29. Obtain the chemical formulæ for the chemical compounds having the following percentage compositions:—

(*a*) CaO, 56 per cent.
CO_2, 44 ,,
Ans. $CaO.CO_2$.

(*b*) PbO, 86·3 per cent.
CO_2, 11·4 ,,
H_2O, 2·3 ,,
Ans. $3PbO.2CO_2.H_2O$.

(*c*) K_2O, 16·9 per cent.
Al_2O_3, 18·3 ,,
SiO_2, 64·8 ,,
Ans. $K_2O.Al_2O_3.6SiO_2$.

(*d*) Al_2O_3, 39·5 per cent.
SiO_2, 46·5 ,,
H_2O, 13·9 ,,
Ans. $Al_2O_3.2SiO_2.2H_2O$.

30. A felspar has the following chemical percentage composition. Calculate its formula, which must be

expressed so as to give the whole of the bases (potash, soda, lime, and magnesia) together equal to unity.

Silica ...	64·63		
Alumina ...	18·95	*Ans.*—	
Lime... ...	1·82	0·167 CaO	
Magnesia ...	0·24	0·031 MgO	$0{\cdot}952\,Al_2O_3; 5{\cdot}53\,SiO_2$.
Potash ...	13·65	0·744 K_2O	
Soda	0·70	0·057 Na_2O	
	100·00	0·999 bases	

It is customary to express the formulæ of glazes on the same lines as are followed in Problem 29—that is, the whole of the monoxides of types R_2O and RO [K_2O, Na_2O, CaO, PbO, ZnO, etc.] are bracketed together, and their total sum is taken as unity. The sesquioxides, R_2O_3 [Al_2O_3, Fe_2O_3], occupy an intermediate position in the formula, and the acid oxides, SiO_2, B_2O_3, are bracketed together at the end. Thus the formulæ are built as follows :—

$$RO.xR_2O_3.y(SiO_2.B_2O_3)$$

Take an example as follows: A fritt has the percentage composition given: calculate its formula.

Silica	56·4
Alumina	13·7
Lime	9·2
Soda	10·0
Boric acid (B_2O_3) ...	10·7
	100·0

Divide as follows :—

56·4 ÷ 60 = 0·94 molecular parts silica
13·7 ÷ 102 = 0·134 „ „ alumina
9·2 ÷ 56 = 0·164 „ „ lime
10·0 ÷ 62 = 0·161 „ „ soda
10·7 ÷ 70 = 0·153 „ „ boric acid

or—

$$\left.\begin{array}{l}0{\cdot}164\ CaO\\0{\cdot}161\ Na_2O\end{array}\right\}0{\cdot}134\ Al_2O_3\left\{\begin{array}{l}0{\cdot}94\ SiO_2\\0{\cdot}153\ B_2O_3\end{array}\right.$$

$$\overline{0{\cdot}325}$$

The total bases amount to 0·325 molecular parts. In order to bring them up to unity the whole formula must be divided throughout by 0·325, which will give—

$$\left.\begin{array}{l}0{\cdot}504\ CaO\\0{\cdot}495\ Na_2O\end{array}\right\}0{\cdot}412\ Al_2O_3\left\{\begin{array}{l}2{\cdot}89\ SiO_2\\0{\cdot}47\ B_2O_3\end{array}\right.$$

31. Calculate the formulæ for the following fritts :—

A.		B.	
Silica	52·6	Silica	25·3
Alumina	12·3	Alumina	5·2
Lime	7·2	Lead oxide	51·2
Magnesia	0·2	Lime	1·3
Soda	8·3	Soda	5·3
Boric acid	19·4	Boric acid	11·7
	100·0		100·0

Ans. A, $\left.\begin{array}{l}0{\cdot}481\ CaO\\0{\cdot}018\ MgO\\0{\cdot}501\ Na_2O\end{array}\right\}0{\cdot}451\ Al_2O_3\left\{\begin{array}{l}3{\cdot}283\ SiO_2.\\1{\cdot}036\ B_2O_3.\end{array}\right.$

B, $\left.\begin{array}{l}0{\cdot}679\ PbO\\0{\cdot}068\ CaO\\0{\cdot}253\ Na_2O\end{array}\right\}0{\cdot}151\ Al_2O_3\left\{\begin{array}{l}1{\cdot}241\ SiO_2.\\0{\cdot}491\ B_2O_3.\end{array}\right.$

32. Calculate the following glazes (hard paste) :—

	A.	B.	C.
Silica	67·5	74·3	73·24
Alumina	14·5	18·3	13·97
Ferric oxide	2·5	—	0·31
Lime	10·0	0·4	2·57
Magnesia	1·0	0·2	0·51
Potash	4·0	6·5	4·81
Soda	0·5	—	1·71
			loss 3·83
	100·0	99·7	100·95

Ans. A, $\left.\begin{matrix} 0{\cdot}702\ CaO \\ 0{\cdot}100\ MgO \\ 0{\cdot}168\ K_2O \\ 0{\cdot}030\ Na_2O \end{matrix}\right\} \left.\begin{matrix} 0{\cdot}561\ Al_2O_3 \\ 0{\cdot}058\ Fe_2O_3 \end{matrix}\right\} 4{\cdot}41\ SiO_2.$

B, $\left.\begin{matrix} 0{\cdot}086\ CaO \\ 0{\cdot}062\ MgO \\ 0{\cdot}852\ K_2O \end{matrix}\right\} 2{\cdot}2\ Al_2O_3;\ 15{\cdot}3\ SiO_2.$

C, $\left.\begin{matrix} 0{\cdot}33\ CaO \\ 0{\cdot}10\ MgO \\ 0{\cdot}37\ K_2O \\ 0{\cdot}20\ Na_2O \end{matrix}\right\} \left.\begin{matrix} 1{\cdot}00\ Al_2O_3 \\ 0{\cdot}01\ Fe_2O_3 \end{matrix}\right\} 9{\cdot}00\ SiO_2.$

33. Calculate the following glazes (earthenware and bone china) :—

	A.	B.	C.
Silica	45·4	53·4	43·4
Alumina	10·9	9·1	9·2
Lead oxide	18·9	17·9	27·6
Lime	6·4	6·2	3·9
Potash	2·9	2·2	7·4
Soda	3·7	3·4	2·5
Boric acid	11·8	7·8	6·0

Ans. A, $\left.\begin{array}{l}0{\cdot}29\ PbO\\0{\cdot}39\ CaO\\0{\cdot}10\ K_2O\\0{\cdot}21\ Na_2O\end{array}\right\}0{\cdot}37\ Al_2O_3\left\{\begin{array}{l}2{\cdot}62\ SiO_2.\\0{\cdot}58\ B_2O_3.\end{array}\right.$

B, $\left.\begin{array}{l}0{\cdot}30\ PbO\\0{\cdot}40\ CaO\\0{\cdot}10\ K_2O\\0{\cdot}20\ Na_2O\end{array}\right\}0\ 33\ Al_2O_3\left\{\begin{array}{l}3{\cdot}31\ SiO_2.\\0{\cdot}41\ B_2O_3.\end{array}\right.$

C, $\left.\begin{array}{l}0{\cdot}40\ PbO\\0{\cdot}21\ CaO\\0{\cdot}25\ K_2O\\0{\cdot}13\ Na_2O\end{array}\right\}0{\cdot}29\ Al_2O_3\left\{\begin{array}{l}2{\cdot}36\ SiO_2\\0{\cdot}28\ B_2O_3\end{array}\right.$

34. Calculate the formula of the following opaque enamel :—

Silica	46·2
Alumina	4·24
Lead oxide	32·12
Tin oxide	9·24
Lime	2·58
Potash	0·67
Soda	4·95

Ans. $\left.\begin{array}{l}0{\cdot}52\ PbO\\0{\cdot}16\ CaO\\0{\cdot}03\ K_2O\\0{\cdot}29\ Na_2O\end{array}\right\}0{\cdot}15\ Al_2O_3\ ;\ 2{\cdot}77\ SiO_2\ ;\ 0{\cdot}23\ SnO_2.$

CHAPTER V.

TO CALCULATE THE PERCENTAGE COMPOSITION OF A SUBSTANCE FROM ITS FORMULA.

It is often desired to obtain the percentage composition of a body when its formula is known. The necessary calculations are exactly the reverse of those in the preceding chapter.

RULE.—*Multiply the molecular parts of each oxide (or atomic parts in the case of an element) by their molecular (or atomic) weights. Add up all the products obtained, and then reduce each to a percentage of the whole sum.*

Examples.—Find the percentage composition of potassium antimoniate ("oxide of antimony"), $K_2Sb_4O_7$.

$$\begin{aligned} K_2 &= 39 \times 2 = 78 \\ Sb_4 &= 120 \times 4 = 480 \\ O_7 &= 16 \times 7 = 112 \\ & \overline{670} \end{aligned}$$

Then—

$$\begin{aligned} \text{Percentage } K &= \tfrac{78}{670} \times 100 = 11{\cdot}64 \text{ per cent.} \\ \text{,, } Sb &= \tfrac{480}{670} \times 100 = 71{\cdot}64 \quad \text{,,} \\ \text{,, } O &= \tfrac{112}{670} \times 100 = 16{\cdot}72 \quad \text{,,} \end{aligned}$$

Find the percentage composition of the following glaze :—

$$\left.\begin{array}{l}0{\cdot}2\ Na_2O\\0{\cdot}3\ CaO\\0{\cdot}5\ PbO\end{array}\right\}0{\cdot}3\ Al_2O_3\left\{\begin{array}{l}2{\cdot}5\ SiO_2\\0{\cdot}5\ B_2O_3\end{array}\right.$$

$0{\cdot}2 \times 62 =$	$12{\cdot}4$	parts soda
$0{\cdot}3 \times 56 =$	$16{\cdot}8$	,, lime
$0{\cdot}5 \times 222 =$	$111{\cdot}0$	,, lead oxide
$0{\cdot}3 \times 102 =$	$30{\cdot}6$	,, alumina
$2{\cdot}5 \times 60 =$	$150{\cdot}0$	,, silica
$0{\cdot}5 \times 70 =$	$35{\cdot}0$	,, boric acid

Total weight of formula ... $355{\cdot}8$

Then—

$$\frac{12{\cdot}4}{355{\cdot}8}\times 100 = 3{\cdot}44\ \%\ Na_2O \qquad \frac{16{\cdot}8}{355{\cdot}8}\times 100 = 4{\cdot}71\ \%\ CaO$$

$$\frac{111}{355{\cdot}8}\times 100 = 31{\cdot}20\ \%\ PbO \qquad \frac{30{\cdot}6}{355{\cdot}8}\times 100 = 8{\cdot}60\ \%\ Al_2O_3$$

$$\frac{150}{355{\cdot}8}\times 100 = 42{\cdot}16\ \%\ SiO_2 \qquad \frac{35}{355{\cdot}8}\times 100 = 9{\cdot}84\ \%\ B_2O_3$$

Hence the percentage composition is—

Silica	42·16
Alumina	8·60
Lead oxide	31·20
Lime	4·72
Soda	3·44
Boric acid	9·84
	99·96

35. Calculate the percentage composition of the following :—

(*a*) PbO. *Ans.* Pb = 92·8 %; O = 7·2 %.

(*b*) $CaCO_3$. ,, Ca = 40 %; C = 12 %; O = 48 %.

(c) $BaSO_4$. *Ans.* Ba = 58·8 %; S = 13·7 %; O = 27·5 %.

(d) $CuSO_4.5H_2O$. ,, Cu = 25·5 %; S = 12·8 %; O = 25·7 ; H O = 36 %.

36. Calculate the percentage composition of the following :—

(a) $Al_2O_3.2SiO_2.2H_2O$. *Ans.* Al_2O_3 = 39·5 % ; SiO_2 = 46·5 % ; H_2O = 14 %.

(b) $Na_2B_4O_7.10H_2O$. ,, Na_2O = 16·2 % ; B_2O_3 = 36·7 % ; H_2O = 47·1 %.

(c) $Pb(OH)_2.2PbCO_3$. ,, PbO = 86·3 % ; CO_2 = 11·4 %; H_2O = 2·3 %.

(d) $K_2Cr_2O_7$. ,, K_2O = 31·8 % ; CrO_3 = 68·1 %.

(e) $K_2SO_4.Al_2(SO_4)_3.24H_2O$. ,, K_2O = 9·9 % ; Al_2O_3 = 10·7 % ; SO_3 = 33·8 % ; H_2O = 45·5 %.

(f) $Ca_3(PO_4)_2$. ,, CaO = 54·2 % ; P_2O_5 = 45·8 %.

37. What are the percentage composition of the glazes and fritts below ?—

$$(a)\quad \left.\begin{array}{l} 0·5\ Na_2O \\ 0·5\ CaO \end{array}\right\} 0·2\ Al_2O_3 \left\{\begin{array}{l} 2·5\ SiO_2. \\ 1·0\ B_2O_3. \end{array}\right.$$

$$(b)\quad \left.\begin{array}{l} 0·75\ PbO \\ 0·15\ CaO \\ 0·10\ Na_2O \end{array}\right\} \begin{array}{l} 2·2\ SiO_2. \\ 0·2\ B_2O_3. \end{array}$$

$$(c)\quad \left.\begin{array}{l} 0·32\ PbO \\ 0·37\ CaO \\ 0·17\ K_2O \\ 0·14\ Na_2O \end{array}\right\} 0·47\ Al_2O_3 \left\{\begin{array}{l} 2·59\ SiO_2. \\ 0·22\ B_2O_3. \end{array}\right.$$

Ans.—

	(a)	(b)	(c)
Silica	50·2	40·3	46·0
Alumina	6·8	—	14·6
Lead oxide	—	50·9	21·4
Lime	9·3	2·5	6·2
Potash	—	—	4·4
Soda	10·3	2·0	2·8
Boric acid	23·4	4·3	4·6
	100·0	100·0	100·0

38. What is the percentage composition of the following pottery bodies?—

(*a*) $\left.\begin{array}{l}0·81\ CaO\\0·06\ K_2O\\0·13\ Na_2O\end{array}\right\}0·09\ Al_2O_3;\ 4·6\ SiO_2.$

(*b*) $\left.\begin{array}{l}0·032\ CaO\\0·030\ MgO\\0·24\ K_2O\\0·063\ Na_2O\end{array}\right\}Al_2O_3;\ 7·7\ SiO_2.$

(*c*) $\left.\begin{array}{l}0·25\ CaO\\0·066\ K_2O\\0·034\ Na_2O\end{array}\right\}Al_2O_3;\ 3·10\ SiO_2.$

(*d*) $\left.\begin{array}{l}0·02\ MgO\\0·067\ K_2O\\0·042\ Na_2O\end{array}\right\}\left.\begin{array}{l}0·98\ Al_2O_3\\0·02\ Fe_2O_3\end{array}\right\}4·732\ SiO_2$

Ans.—

	(a)	(b)	(c)	(d)
Silica	80·31	78·1	60·0	71·90
Alumina	2·62	17·0	33·0	25·33
Ferric oxide ...	—	—	—	0·63
Lime	13·27	0·3	4·5	—
Magnesia ...	—	0·2	—	0·24
Potash	1·64	3·75	2·0	1·14
Soda	2·30	0·65	0·7	0·65
	100·14	100·0	100·2	99·89

39. Given the following formulæ for pegmatite or Cornish stone, calculate the percentage composition :—

$$(a)\ \left.\begin{matrix}0{\cdot}043\ CaO\\ 0{\cdot}204\ K_2O\\ 0{\cdot}387\ Na_2O\end{matrix}\right\}Al_2O_3;\ 7{\cdot}54\ SiO_2.$$

$$(b)\ \left.\begin{matrix}0{\cdot}034\ MgO\\ 0{\cdot}360\ K_2O\\ 0{\cdot}071\ Na_2O\end{matrix}\right\}Al_2O_3;\ 6{\cdot}81\ SiO_2.$$

$$(c)\ \left.\begin{matrix}0{\cdot}061\ CaO\\ 0{\cdot}687\ K_2O\end{matrix}\right\}Al_2O_3;\ 8{\cdot}50\ SiO_2.$$

Ans.—

	(a)	(b)	(c)
Silica	75·4	74·3	75·0
Alumina	17·0	18·5	15·0
Lime	—	0·24	—
Magnesia	0·4	—	0·5
Potash	3·2	6·16	9·5
Soda	4·0	0·8	—
	100·0	100·0	100·0

CHAPTER VI.

THE COMPOUNDING OF MIXTURES OF DEFINITE COMPOSITION FROM SUBSTANCES OF KNOWN CHEMICAL COMPOSITION.

It is in building up mixtures of varying complexity, whose percentage compositions or formulæ are known, from materials with given composition, that the utility of formulæ is most apparent. The calculation necessary is much curtailed, and the real significance of the various steps is more plainly seen than when percentage composition only is used.

Suppose, for example, that a glaze is to be synthesised containing 0·3 molecular part of soda; it is at once evident that 0·3 molecular part of any substance containing 1 molecular part of soda must be used. If the raw material to be used contains but half a molecular part of soda, then plainly 0·6 of a molecular part of that material will be necessary. On the other hand, if the raw material contains 2 molecular parts of soda, then only half of 0·3 (*i.e.* 0·15) molecular part must be taken. Again, if say 3 molecular parts of silica are to be present in the synthesised mixture, one may use 3 molecular parts of any substance which contains 1 molecular part of silica, 1·5 molecular part of any substance containing 2 molecules of silica,

1 molecular part of such as contain 3 molecules of silica, and so on.

Thus, 3 molecular parts silica ($3SiO_2$) could be obtained from 3 molecular parts of potassium silicate (K_2SiO_3), or 1·5 molecular part of kaolinite ($Al_2O_3.2SiO_2.2H_2O$), or 0·5 molecular part of felspar ($K_2O.Al_2O_3.6SiO_2$). The molecular weights of the various compounds are obtained by simply adding together the weights of all the atoms contained in them. Hence the rule :—

To introduce any given molecular quantity of a substance, multiply the molecular weight of the raw material by the molecular parts of the substance required, and divide by the number of molecules of that substance which are present in each molecule of the raw material.

Thus, to introduce 1·50 SiO_2 into a glaze, using felspar with the formula $K_2O.Al_2O_3.6SiO_2$, proceed as follows: The molecular weight of the felspar is found, by reference to the table of molecular weights of the oxides it contains, to be $94 + 102 + 360 = 556$. Then—

$$\frac{556 \times 1{\cdot}50}{6} = \mathbf{139} \text{ parts of felspar}$$

Again, to introduce 0·37 CaO as commercial whiting, the formula for which is—

$$CaO.\begin{cases} 0{\cdot}0016\ Fe_2O_3.0{\cdot}0122\ SiO_2 \\ 0{\cdot}0072\ Al_2O_3.1{\cdot}002\ CO_2 \end{cases}$$

The molecular weight of the whiting is found to be—

$$56 + 0{\cdot}256 + 0{\cdot}734 + 0{\cdot}732 + 44{\cdot}088 = \mathbf{101{\cdot}810}$$

Then—

$$\frac{101{\cdot}810 \times 0{\cdot}37}{1} = \mathbf{37{\cdot}66} \text{ parts whiting}$$

40. Calculate the weight of felspar, china clay, Cornish stone, and sand, respectively, which would be required to introduce 1·75 SiO_2 into a pottery body. The formulæ for the raw materials are those given for felspar in Question 30: china clay, $0{\cdot}05\ K_2O.Al_2O_3.2{\cdot}2\ SiO_2.2{\cdot}1\ H_2O$; Cornish stone is that given under (*a*) Question 39; and the sand is $0{\cdot}01\ Al_2O_3.SiO_2$.

Ans. **162** felspar; **220** china clay; **139** Cornish stone; **106·8** sand.

41. It is desired to add to a glaze 0·2 PbO as a fritt whose formula is $\left.\begin{matrix}0{\cdot}5\ Na_2O\\0{\cdot}5\ PbO\end{matrix}\right\}0{\cdot}2\ Al_2O_3\left\{\begin{matrix}2\ SiO_2\\B_2O_3\end{matrix}\right.$. What amount of fritt must be used?

Ans. **140·96.**

It is, however, evident that in most cases other substances, in addition to the desired one, are added simultaneously. In order that these additional substances may be allowed for, their amount must be known. It is at once seen, for instance, that in Question 41, in addition to the 0·2 PbO, there are also added the same molecular quantity, viz. 0·2 Na_2O, two-fifths of 0·2, *i.e.* 0·08 Al_2O_3; four times 0·2, *i.e.* 0·8 SiO_2; and twice 0·2, *i.e.* 0·4 B_2O_3. The numbers are not so readily obtained with more complex formulæ. For example, the following is the formula for a crystalline glaze:—

$$\left.\begin{matrix}0{\cdot}28\ K_2O\\0{\cdot}50\ Na_2O\\0{\cdot}08\ CaO\\0{\cdot}14\ BaO\end{matrix}\right\}0{\cdot}12\ Al_2O_3\left\{\begin{matrix}4{\cdot}82\ SiO_2\\1{\cdot}00\ B_2O_3\end{matrix}\right\}+1{\cdot}67\ ZnO$$

Suppose it is desired to add to another glaze a

quantity of this crystalline glaze containing 1·5 molecular parts of ZnO. The amount required will be found to be 530 parts. The molecular parts of K_2O will be $\frac{1·5}{1·67}$ of 0·28 = 0·252 K_2O, and so throughout the formula. That is to say, all the oxides of the formula will be diminished in the ratio $\frac{1·5}{1·67}$.

42. 0·37 Na_2O is introduced into a glaze (*a*) as borax ($Na_2B_4O_7.10H_2O$); (*b*) as soda ash (Na_2CO_3); (*c*) as a fritt—

$$\left.\begin{array}{l} 0·3\ Na_2O \\ 0·3\ Ka_2O \\ 0·2\ CaO \\ 0·2\ PbO \end{array}\right\} 0·35\ Al_2O_3 \left\{\begin{array}{l} 2·5\ SiO_2 \\ 0·6\ B_2O_3 \end{array}\right.$$

Calculate the molecular parts of other substances introduced at the same time, and remaining in the fused glaze, and the weight of the fritt (*c*) which will be necessary.

Ans. (*a*) 0·74 B_2O_3; (*b*) nil; (*c*) 0 37 K_2O, 0·25 CaO, 0·25 PbO, 0·43 Al_2O_3, 3·08 SiO_2, 0·74 B_2O_3. 407 parts of the fritt would be required.

43. Cornish stone (b), Question 39, is used as a means of introducing 0·3 K_2O into a fritt. What weight is required, and what molecular proportions of the other oxides are added simultaneously?

Ans. 458 parts of stone; 0·028 MgO, 0·059 Na_2O, 0·83 Al_2O_3, 5·67 SiO_2.

44. China clay—

$$\left[\begin{array}{l} 0·010\ CaO \\ 0·013\ MgO \\ 0·070\ (NaK)_2O \end{array}\right\} \left.\begin{array}{l} 0·99\ Al_2O_3 \\ 0·01\ Fe_2O_3 \end{array}\right\} 1·99\ SiO_2,\ 1·83\ H_2O \Bigg]$$

is used to introduce 0·5 SiO_2 into a glaze. What amount will be required, and what molecular parts of the other oxides are simultaneously introduced? The molecular weight of the alkalies is to be taken as 78.

Ans. 65·7 parts of clay; 0·0025 CaO, 0·0033 MgO, 0·0176 $(NaK)_2O$, 0·249 Al_2O_3, 0·0025 Fe_2O_3, 0·46 H_2O.

CHAPTER VII.

TO APPLY THE METHODS OF THE PRECEDING SECTION IN THE COMPLETE SYNTHESIS OF MIXTURES OF KNOWN FORMULÆ FROM RAW MATERIALS OF GIVEN COMPOSITION.

PLACE in a line at the head of separate columns the individual oxides in the formula, with their coefficients. Observe which of the oxides of the mixture are introduced as single raw materials, and calculate the weight of these raw materials necessary for the formula. Calculate the molecular parts of the other oxides added simultaneously, and subtract each from the original amounts required. Proceed to calculate the amounts of the remaining materials required to make up the whole formula, preferably leaving the completion of the silica and alumina to the last.

Thus, to build up a fritt—

$$\left.\begin{matrix} 0{\cdot}5\ Na_2O \\ 0{\cdot}5\ PbO \end{matrix}\right\} 0{\cdot}2\ Al_2O_3 \left\{\begin{matrix} 2{\cdot}5\ SiO_2 \\ 1{\cdot}0\ B_2O_3 \end{matrix}\right.$$

using borax, pure ($Na_2B_4O_7.10H_2O$); red lead (Pb_3O_4); pure china clay ($Al_2O_3.2SiO_2.2H_2O$); flint (SiO_2).

	0·5 Na_2O.	0·5 PbO.	0·2 Al_2O_3.	2·5 SiO_2.	1·0 B_2O_3.
Pb_3O_4 mol. wt. = 683; $\frac{683}{3} \times 0·5 = 114$ red lead	—	0·5 PbO	—	—	—
$Na_2B_4O_7.10H_2O = 382$; $\frac{382}{1} \times 0·5 = 191$ borax	0·5 Na_2O	—	—	—	1·0 B_2O_3
$Al_2O_3.2SiO_2.2H_2O = 258$; $\frac{258}{1} \times 0·2 = 51·6$ china clay	—	—	0·2 Al_2O_3	0·4 SiO_2	—
$SiO_2 = 60$; $60 \times 2·1 =$ 126 flint	—	—	—	2·1 SiO_2	—
	0·5 Na_2O	0·5 PbO	0·2 Al_2O_3	2·5 SiO_2	1·0 B_2O_3

The amount of red lead required to give 0·5 PbO is first calculated. Then the borax to produce 0·5 Na_2O is found, and simultaneously the boric acid which it introduces. Alumina is next added as china clay, and the balance of silica as flint.

To take a more complex case. Build up the enamel of Question 34, using—

(*a*) Calcine, containing 68 per cent. PbO, and 32 per cent. SnO_2.

(*b*) White lead [$Pb(OH)_2.2PbCO_3$].

(*c*) Soda ash (Na_2CO_3).

(*d*) China clay, Question 44.

(*e*) Flint, 96 per cent. SiO_2, 4 per cent. $CaCO_3$.

	0·56 PbO.	0·10 CaO.	0·03 K_2O.	0·31 Na_2O.	0·16 Al_2O_3.	3·0 SiO_2.	0·23 SnO_2.
108 calcine ...	0·33	—	—	—	—	—	0·23
59·2 white lead	0·23	—	—	—	—	—	—
32·86 soda ash	—	—	—	0·31	—	—	—
42·2 china clay	—	{0·002 / 0·0021 MgO}	0·013	—	0·16	0·33	—
167 flint ...	—	0·0667	—	—	—	2·67	—
	0·56	0·0709	0·013	0·31	0·16	3·0	0·23

Formula for calcine = $PbO.0{\cdot}696\ SnO_2$; molecular weight = 326·8, say 327.

To introduce 0·23 SnO_2 requires $\frac{327}{0{\cdot}696} \times 0{\cdot}23$ = 108 parts.

This amount of calcine introduces $\frac{0{\cdot}23}{0{\cdot}696} \times 1$ = 0·33 PbO.

There thus remains 0·56 − 0·33 = 0·23 PbO to be introduced as white lead. Molecular weight of white lead = 773, but the molecule contains 3 molecules PbO.

∴ amount required = $\frac{773}{3} \times 0{\cdot}23$ = **59·2** white lead

Soda is the next oxide in any abundance in the formula (except Al_2O_3 and SiO_2, which are dealt with last).

0·31 Na_2O is required, which will be obtained from soda ash; molecular weight Na_2CO_3 = 106. Hence $\frac{106}{1} \times 0{\cdot}31$ = 32·86 soda ash in the batch weight.

Now, the china clay contains potash, alumina, and lime. Calculate the quantity required for 0·16 Al_2O_3. Molecular weight of the clay is 261·9.

$$\text{Hence } \frac{261{\cdot}9}{0{\cdot}99} \times 0{\cdot}16 = \mathbf{42{\cdot}2} \text{ china clay}$$

Calculate also the oxides accompanying the alumina in the clay, thus—

$$CaO \left[= \frac{0{\cdot}010}{0{\cdot}99} \times 0{\cdot}16 =\right] 0{\cdot}002$$

$$MgO \left[= \frac{0{\cdot}013}{0{\cdot}99} \times 0{\cdot}16 =\right] 0{\cdot}0022$$

$$K_2O \left[= \frac{0{\cdot}070}{0{\cdot}99} \times 0{\cdot}16 =\right] 0{\cdot}013$$

$$SiO_2 \left[= \frac{1{\cdot}99}{0{\cdot}99} \times 0{\cdot}16 =\right] 0{\cdot}32$$

Placing these amounts in their respective columns, MgO going with CaO, there then remains to be added 0·0958 CaO ; 0·017 K_2O ; 2·67 SiO_2.

The silica is now added as flint. Formula = 0·025 $CaO.SiO_2$; molecular weight = **62·5**.

$$\therefore \frac{62 \cdot 5}{1} \times 2 \cdot 67 = \mathbf{167} \text{ parts of flint}$$

This amount of flint contains also 0·025 × 2·67 = 0·0667 CaO.

Now, summing up the amounts of each oxide which has been introduced, it is seen that there is a deficiency of 0·0291 CaO[= 2·91 parts pure carbonate of lime] and 0·017 K_2O. The latter cannot be introduced with the raw materials at disposal. Hence the recipe for the enamel would become—

108·0 calcine
59·2 white lead
32·9 soda ash
42·2 china clay
167·0 flint
[3·0 whiting or chalk]

45. Using pure flint and white lead, what would be the recipe for a fritt $PbO.SiO_2$?

Ans. 257·6 white lead ; 60 flint.

46. What would be the recipe for a matt blue base having the formula $CoO.Al_2O_3$, using black oxide of cobalt and potash alum?

Ans. 165 oxide of cobalt ; 948 alum.

47. A flow powder is to be made, having the composition represented by $CaCl_2.PbCl_2$. What proportions of whiting and red lead would be used? And what weight of flow powder would be obtained from 1 cwt. of whiting?

Ans. 100 whiting ; 228 red lead ; 434 lbs.

48. It is desired to make 1 cwt. of tin ash, having a formula $PbO.SnO_2$. How much metallic tin and metallic lead would be used?

Ans. 62 lbs. lead; $35\frac{1}{2}$ lbs. tin.

49. How much pure litharge and potassium bichromate would be required to make 28 lbs. lead chromate?

Ans. 19·3 litharge; 12·8 potassium bichromate.

50. Using pure borax, felspar ($K_2O.Al_2O_3.6\ SiO_2$), flint, whiting, and china clay, build up a recipe to produce the following fritt:—

$$\left.\begin{array}{l} 0{\cdot}3\ Na_2O \\ 0{\cdot}2\ K_2O \\ 0{\cdot}5\ CaO \end{array}\right\}\ 0{\cdot}4\ Al_2O_3 \left\{\begin{array}{l} 2{\cdot}2\ SiO_2 \\ 0{\cdot}6\ B_2O_3 \end{array}\right.$$

Ans. 114·6 borax; 111·2 felspar; 50 whiting; 51·6 china clay; 36 flint.

51. From red lead, whiting, soda ash, boric acid, china clay, Cornish stone ($K_2O.Al_2O_3.8{\cdot}5\ SiO_2$), and flint, put together a recipe which will yield the following fritt, and find the weight of the fritt which the batch should give from the kiln—

$$\left.\begin{array}{l} 0{\cdot}2\ Na_2O \\ 0{\cdot}1\ K_2O \\ 0{\cdot}3\ CaO \\ 0{\cdot}4\ PbO \end{array}\right\}\ 0{\cdot}3\ Al_2O_3 \left\{\begin{array}{l} 2{\cdot}5\ SiO_2 \\ 0{\cdot}3\ B_2O_3 \end{array}\right.$$

Ans.—

Soda ash	21·2
Whiting	30·0
Red lead	91·0
Stone	70·6
China clay	51·6
Flint	75·0
Crystallized boric acid ...	37·2
	378·6 yield **329** of fritt

52. Assuming in Question 51 that the flint, stone, and clay, contain 5, 7, and 4 per cent. of moisture respectively, what would be their batch weight in the above recipe?

Ans. Flint, 79; stone, 76; china clay, 53·75.

53. It is required to build up the following glaze from pure borax, boric acid cryst., felspar, whiting, china clay, and flint. Calculate the batch weights:—

Silica	...	50·40 per cent.
Alumina	...	12·14 ,,
Lime ...	...	12·52 ,,
Soda ...	...	8·34 ,,
Potash	...	2·50 ,,
Boric acid	...	10·65 ,,
Carbon dioxide		2·53 (present as carbonate of lime)

Ans. 58·2 whiting; 133·3 borax; 5·8 cryst. boric acid; 38·5 felspar; 62 china clay; 77·5 flint.

54. From red lead, whiting, borax, felspar, china clay, and flint, all supposed to be pure, build up the fritt having the composition—

Silica ...	...	...	54·8
Alumina	...	...	7·5
Lead oxide	...	...	22·0
Lime ...	...	...	8·3
Alkalies	...	...	3·9
Boric acid	...	...	3·5

and give the formula of the fritt.

Ans. $$\left.\begin{matrix} 0\cdot33\ PbO \\ 0\cdot50\ CaO \\ 0\cdot17\ (NaK)_2O \end{matrix}\right\}\ 0\cdot25\ Al_2O_3 \left\{\begin{matrix} 3\cdot083\ SiO_2. \\ 0\cdot17\ B_2O_3. \end{matrix}\right.$$

76 red lead; 50 whiting; 32·5 borax; 47·3 felspar; 43 china clay; 134·6 flint.

55. Calculate the formula of the fritt and glaze made according to the following recipe, after firing :—

Fritt, 33·9 flint	fritt, 67
11·1 china clay	Cornish stone, 21
18·8 boric acid	china clay, 2·5
18·8 whiting	white lead, 9·5
8·4 soda	
9·0 red lead	

assuming materials to be pure, and the Cornish stone to be $K_2O.1{\cdot}12\ Al_2O_3.8{\cdot}84\ SiO_2$[mol. wt. = 738·6].

Ans.—

$$\text{Fritt} = \left\{\begin{array}{l} 0{\cdot}257\ Na_2O \\ 0{\cdot}613\ CaO \\ 0{\cdot}130\ PbO \end{array}\right\} 0{\cdot}14\ Al_2O_3 \left\{\begin{array}{l} 2{\cdot}12\ SiO_2. \\ 0{\cdot}492\ B_2O_3. \end{array}\right.$$

$$\text{Glaze} = \left\{\begin{array}{l} 0{\cdot}29\ (NaK)_2O \\ 0{\cdot}485\ CaO \\ 0{\cdot}225\ PbO \end{array}\right\} 0{\cdot}238\ Al_2O_3 \left\{\begin{array}{l} 2{\cdot}5\ SiO_2. \\ 0{\cdot}39\ B_2O_3. \end{array}\right.$$

CHAPTER VIII.

FROM A POTTER'S RECIPE, TO CALCULATE THE FORMULA OF A GLAZE OR FRITT.

THIS operation is one of great utility. If the composition of the raw materials used in the recipe is known, the formula of the mixture can be calculated, and a very clear insight is obtained into the properties of the glaze, its defects or qualities, and, in the former case, the path is readily seen to a remedy. This is, however, true only if the composition of the raw materials is known. If assumptions are made as to the probable purity or otherwise of these substances, the method at once loses much of its value.

It is only when thus reckoned out that similarities and differences between glazes and fritts can be recognized. It will be often found that under apparently the most diverse recipes is hidden the same glaze. Comparison and contrast are very much facilitated by the expression of the mixtures by means of their formulæ.

(*a*) To find the formula of a raw mixture is straightforward. Assuming that the composition of the raw materials is known, proceed as follows: Divide a sheet of paper into columns to accommodate the name and amount of the raw materials and each of the several oxides entering into the mixtures, each in its own column. From the composition given for the raw

materials, calculate the amounts of each oxide added in the form of each ingredient. Then sum up the various amounts of each oxide, and deduce the formula by the methods of Chapter IV., p. 24 *et seq.*

Thus, calculate the formula of the following glaze :—

65 white lead
25 stone
7 flint
3 china clay

The white lead is to be taken as $Pb(OH)_2.2PbCO_3$; stone same as (*b*) No. 39; flint, 96 per cent. SiO_2, 4 per cent. $CaCO_3$; china clay is 45·89 SiO_2, 38·89 Al_2O_3, 0·51 Fe_2O_3, 2·87 alkalies, 12·28 H_2O.

Then—

$$65 \text{ white lead} = \frac{667{\cdot}2}{773} \times 65 = 56{\cdot}1 \text{ PbO}$$

because molecular weight white lead = 773, of which 3 × 222·4 is lead oxide.

25 stone = 18·6 parts SiO_2, 4·6 Al_2O_3, 0·06 MgO, 1·54 K_2O, 0·02 Na_2O

7 flint = 6·72 SiO_2, 0·28 $CaCO_3$ = 0·157 CaO

3 china clay = 1·37 SiO_2, 1·16 Al_2O_3, 0·015 Fe_2O_3, 0·86 alkalies

Putting the whole in tabular form—

	PbO.	CaO.	MgO.	Alk.	Al_2O_3.	Fe_2O_3.	SiO_2.
65 white lead ...	56·1	—	—	—	—	—	—
25 stone	—	—	0·06	$\begin{Bmatrix}1{\cdot}54\\0{\cdot}02\end{Bmatrix}$	4·6	—	18·6
7 flint	—	0·157	—	—	—	—	6·72
3 china clay ...	—	—	—	0·86	1·16	0·015	1·37
Parts by weight	56·1	0·157	0·06	2·42	5·76	0·015	26·69

$$56{\cdot}1 \text{ lead oxide} = \frac{56{\cdot}1}{222{\cdot}4} = 0{\cdot}252 \text{ PbO molecular parts}$$

$$0{\cdot}157 \text{ lime} = \frac{0{\cdot}157}{56} = 0{\cdot}0027 \text{ CaO}$$

$$0{\cdot}06 \text{ magnesia} = \frac{0{\cdot}06}{40} = 0{\cdot}0015 \text{ MgO}$$

$$2{\cdot}42 \text{ alkalies} = \frac{2{\cdot}42}{78} = 0{\cdot}031 \text{ alkalies (assuming } \tfrac{1}{2}K_2O.\tfrac{1}{2}Na_2O)$$

$$5{\cdot}76 \text{ alumina} = \frac{5{\cdot}76}{102} = 0{\cdot}056\ Al_2O_3$$

$$0{\cdot}015 \text{ ferric oxide} = \frac{0{\cdot}015}{160} = 0{\cdot}0001\ Fe_2O_3$$

$$26{\cdot}69 \text{ silica} = \frac{26{\cdot}69}{60} = 0{\cdot}4448\ SiO_2$$

The total bases add up to 0·2872. Dividing throughout each coefficient by this number, we get—

$$\left.\begin{array}{l} 0{\cdot}878\ PbO \\ 0{\cdot}008\ CaO \\ 0{\cdot}005\ MgO \\ 0{\cdot}108\ (NaK)_2O \end{array}\right\} \left.\begin{array}{l} 0{\cdot}195\ Al_2O_3 \\ 0{\cdot}0004\ Fe_2O_3 \end{array}\right\} 1{\cdot}56\ SiO_2$$

$$\overline{0{\cdot}999}$$

In the case of a fritted glaze there is introduced the complication of the fritt. This renders it necessary to calculate what proportions of the raw materials are represented by the fritt in the mixed glaze. These numbers may be obtained in several ways. If the weight of fritt obtained from the fritt kiln per batch is known (which will be the case in well-conducted works), it is a simple matter to reckon the equivalent amounts

of raw material corresponding to the weight of fritt added to the glaze mixing.

If, however, this weight is not known, it can be found by calculation on the following lines. In the first place, all materials will be considered as dry. The loss of weight on the kiln is due to water, organic matter, oxygen, and carbon dioxide, which are liberated by the effect of the fire or mutual chemical action of the ingredients.

Thus, white lead loses water and carbon dioxide; red lead loses oxygen; whiting or Paris white loses carbon dioxide; Cornish stone and china clay lose water; borax and boric acid lose water of crystallization; soda ash loses carbon dioxide. It may, in fact, be imagined that the various compounds are reduced to the condition of free anhydrous oxides, which then combine to form the fritt, though there is actually no evidence of such decomposition. The amount of these losses can often be calculated from the percentage composition of the materials and from their formulæ. In other cases they may be found by firing the materials through the oven.

Thus, calculate the formula of the following fritted glaze:—

I. Borax fritt—
98 cryst. borax
200 felspar
50 whiting
50 flint

II. Lead fritt—
125 red lead
20 felspar
20 flint
20 china clay

Glaze: 100 fritt I.
25 fritt II.
10 flint
25 china clay

To first find the weight of fritt I. obtained per charge from the kiln (assuming materials to be dry).

Borax loses water ($Na_2B_4O_7.10H_2O$)—that is, 382 of borax becomes 202; therefore 98 crystal borax become **51·8** from the kiln.

Felspar does not lose anything if dry and pure. It may, however, contain about 5 per cent. whiting. Assuming this composition (95 per cent. felspar, 5 per cent. whiting), 200 of felspar will lose $10 \times \frac{44}{100} = 4·4$, or 200 felspar becomes **195·6**, because $CaCO_3$ becomes CaO, a loss of 44 on every 100 of carbonate of lime; 50 whiting becomes $50 \times \frac{56}{100} =$ **28** parts lime; 50 flint, if pure, loses nothing.

Thus sum up as follows:—

98 borax	yields	51·8
200 felspar	„	195·6
50 whiting	„	28·0
50 flint	„	50·0
398 charge	„	325·4 of fritt

Now, the 100 of fritt in the glaze mixture will be equal to—

$$\left.\begin{array}{l} \frac{100}{325} \text{ of } 98 = 30·2 \text{ borax} \\ \frac{100}{325} \text{ „ } 200 = 61·2 \text{ felspar} \\ \frac{100}{325} \text{ „ } 50 = 15·3 \text{ whiting} \\ \frac{100}{325} \text{ „ } 50 = 15·3 \text{ flint} \end{array}\right\} \text{Fritt I. in glaze mixture.}$$

Now, the lead fritt II.—

Red lead (pure) loses oxygen ($Pb_3O_4 - O = 3PbO$)—that is, 683 loses 16, and becomes 667;

$\therefore$ 125 red lead becomes $125 \times \frac{667}{683} = \mathbf{122}$ lead oxide ;

20 of felspar, as above, becomes **19·56** in the fritt ;

20 of flint loses **20** ;

20 of china clay used in preceding example loses $12{\cdot}28 \times \frac{20}{100} = 2{\cdot}46$ water, and becomes reduced to **17·54** in the fritt.

Thus—

125 red lead	yields	122·0
20 felspar	„	19·56
20 flint	„	20·0
20 china clay	„	17·54
185 batch	„	**179·1** of fritt II.

Then the amount of lead fritt (25) in the glaze contains—

$\frac{25}{179}$ of 125 = 17·4 red lead
$\frac{25}{177}$ „ 20 = 2·8 felspar
$\frac{25}{177}$ „ 20 = 2·8 flint
$\frac{25}{177}$ „ 20 = 2·8 china clay

The whole glaze therefore contains—

Fritt I.	Fritt II.	Added raw.	Total.
30·2 borax	—	—	30·2 borax
61·2 felspar	2·8 felspar	—	64·0 felspar
15·3 whiting	—	—	15·3 whiting
15·3 flint	2·8 flint	10 flint	28·1 flint
—	2·8 china clay	25 china clay	27·8 china clay
—	17·4 red lead	—	17·4 red lead

Now, from this glaze recipe, given in terms of raw material, calculate the formula as in the preceding example.

$$\textit{Ans.}\ \left.\begin{array}{l}0{\cdot}437\ (NaK)_2O\\ 0{\cdot}398\ CaO\\ 0{\cdot}164\ PbO\end{array}\right\}0{\cdot}462\ Al_2O_3\left\{\begin{array}{l}2{\cdot}86\ SiO_2.\\ 0{\cdot}365\ B_2O_3.\end{array}\right.$$

56. Calculate the formulæ of the following raw glazes:—

(*a*) 54 white lead, 20 flint, 15 china clay, 11 felspar.
(*b*) 278 felspar, 50 whiting, 120 flint.
(*c*) 38 litharge, 4 chalk, 28 Cornish stone, 19 flint.
(*d*) 27 sand, 13 china clay, 42 felspar, 17·7 whiting.

Assuming in each case the white materials are pure, and the Cornish stone is (*b*) No. 39.

$$\textit{Ans.}\ (a)\ \left.\begin{array}{l}0{\cdot}91\ PbO\\ 0{\cdot}09\ K_2O\end{array}\right\}0{\cdot}34\ Al_2O_3.2{\cdot}47\ SiO_2.$$

$$(b)\ \left.\begin{array}{l}0{\cdot}5\ K_2O\\ 0{\cdot}5\ Na_2O\end{array}\right\}0{\cdot}5\ Al_2O_3.2{\cdot}3\ SiO_2.$$

$$(c)\ \left.\begin{array}{l}0{\cdot}298\ K_2O\\ 0{\cdot}702\ CaO\end{array}\right\}0{\cdot}49\ Al_2O_3.3{\cdot}97\ SiO_2.$$

57. What weight of fritt would be obtained from the kiln by melting the following mixtures?—

(*a*) 100 flint, 25 whiting, 200 red lead, 70 boric acid (crystals).
(*b*) 250 red lead, 130 flint, 75 borax crystals.
(*c*) 30 borax, 17 sand, 31 stone, 11 china clay, 11 whiting.

(All materials pure; stone (*b*) No. 39.)

Ans. (*a*) 349·5; (*b*) 414; (*c*) 78·5.

58. Give the formulæ of the above fritts (No. 57).

$$\textit{Ans.}\ (a)\ \left.\begin{array}{l}0{\cdot}78\ PbO\\ 0{\cdot}22\ CaO\end{array}\right\}-\left\{\begin{array}{l}1{\cdot}48\ SiO_2.\\ 0{\cdot}50\ B_2O_3.\end{array}\right.$$

$$(b)\ \left.\begin{array}{l}0{\cdot}85\ PbO\\ 0{\cdot}15\ Na_2O\end{array}\right\}-\left\{\begin{array}{l}1{\cdot}67\ SiO_2.\\ 0{\cdot}30\ B_2O_3.\end{array}\right.$$

$$(c)\ \left.\begin{array}{l}0{\cdot}387\ Na_2O\\ 0{\cdot}094\ K_2O\\ 0{\cdot}52\ CaO\end{array}\right\}0{\cdot}46\ Al_2O_3\left\{\begin{array}{l}3{\cdot}54\ SiO_2.\\ 0{\cdot}736\ B_2O_3.\end{array}\right.$$

59. Calculate the formulæ of the following glazes, assuming materials to be pure and dry :—

(*a*) Fritt: 41 stone ((*b*) No. 39), 24 flint, 32 borax crystals.

Glaze: 59 fritt, 18·5 white lead, 11 stone ((*b*) No. 39).

(*b*) Fritt: 11 china clay, 25 felspar, 58 flint, 6 carbonate of potash.

Glaze: 15 fritt, 39 china clay, 39 felspar.

(*c*) Fritt: 12 china clay, 20 stone ((*b*) No. 39), 15 flint, 18 whiting, 35 borax.

Glaze: 65 fritt, 11 Cornish stone ((*b*) No. 39), 11 flint, 13 white lead.

Ans. (*a*) $\left.\begin{array}{l}0{\cdot}032\ K_2O\\0{\cdot}080\ Na_2O\\0{\cdot}888\ PbO\end{array}\right\}0{\cdot}09\ Al_2O_3\left\{\begin{array}{l}0{\cdot}97\ SiO_2.\\0{\cdot}148\ B_2O_3.\end{array}\right.$

(*b*) $K_2O,\ 2{\cdot}9\ Al_2O_3.11{\cdot}4\ SiO_2.$

(*c*) $\left.\begin{array}{l}0{\cdot}055\ K_2O\\0{\cdot}270\ Na_2O\\0{\cdot}513\ CaO\\0{\cdot}162\ PbO\end{array}\right\}0{\cdot}29\ Al_2O_3\left\{\begin{array}{l}2{\cdot}72\ SiO_2.\\0{\cdot}52\ B_2O_3.\end{array}\right.$

60. Calculate the formulæ of the following fluxes :—

(*a*) 3 red lead, 2 borax, 1 flint.
(*b*) 73 lead oxide, 18 flint, 9 fused borax.
(*c*) 60 red lead, 15 flint, 25 fused borax.
(*d*) 3 red lead, 1 flint.

Ans. (*a*) $\left.\begin{array}{l}0{\cdot}285\ Na_2O\\0{\cdot}715\ PbO\end{array}\right\}\begin{array}{l}0{\cdot}9\ SiO_2.\\0{\cdot}57\ B_2O_3.\end{array}$

(*b*) $\left.\begin{array}{l}0{\cdot}119\ Na_2O\\0{\cdot}881\ PbO\end{array}\right\}\begin{array}{l}0{\cdot}805\ SiO_2.\\0{\cdot}239\ B_2O_3.\end{array}$

(*c*) $\left.\begin{array}{l}0{\cdot}32\ Na_2O\\0{\cdot}68\ PbO\end{array}\right\}\begin{array}{l}0{\cdot}645\ SiO_2.\\0{\cdot}64\ B_2O_3.\end{array}$

(*d*) $PbO.1{\cdot}26\ SiO_2.$

CHAPTER IX.

THE RATIONAL ANALYSIS OF CLAYS, AND THE METHODS OF CALCULATION BASED UPON IT.

CONSIDERABLE information about the properties of a clay may be obtained from its chemical composition. Though chemical composition and physical properties are not so closely dependent upon each other in the clays as they are in glazes and fritts, fairly accurate forecasts of the behaviour of clays under physical forces may be made. This is true to a greater degree when the rational analyses of the clays are known than when only the ultimate analyses are available. In the latter case the information imparted is the total amounts of each of the individual oxides comprising the clay, and no regard is paid to the combinations in which these oxides occur. For instance, silica is the same in the eyes of the ultimate analysis, no matter whether it is in the free state or is derived from felspar or clay substance. But there cannot be the slightest doubt that the properties of clay will be different according to the manner in which the silica and other oxides occur. This is true so long as the clay is not fused to a glass; that is, it is true for all temperatures to which the clay will be subjected in the processes of pottery manufacture. Probably, if the clay is actually fused, there will not be a great difference between the effects of the

silica in its several modes of occurrence, for the mixture comprising the clay becomes transformed into a more or less homogeneous glassy mass, consisting of new arrangements of the oxides of the clays. If, however, the temperature is much lower, there will evidently be introduced differences of behaviour, due to the actual mineral constitution of the clays.

It is the object of the rational analysis to discover the actual mineral components of the clays; it seeks to find out how much hydrated silicate of alumina (clay substance), felspar, and quartz, etc., there may be present.

The method of analysis is based first on the action of hot strong sulphuric acid on clay substance, which it decomposes with the formation of sulphate of alumina and free silica—

$$Al_2O_3.2SiO_2.2H_2O + 3H_2SO_4 = Al_2(SO_4)_3 + 2SiO_2 + 5H_2O$$

The sulphate of alumina is soluble in acidulated water, and the silica in warm dilute alkaline solutions. By alternate treatment of the mass obtained by this reaction on a clay with acidulated water and solution of soda, these products of the decomposition of the clay substance are removed. The loss of weight which has taken place in the substance under examination is taken as clay substance, after allowance has been made for organic matter which may exist in many clays.

The remainder is considered to be felspar (orthoclase) and quartz. It is assumed that the felspar agrees with the formula $K_2O.Al_2O_3.6SiO_2$, in which the ratio of alumina to silica is 102 : 360, or 1 : 3·53. It is therefore argued that if the alumina left in the residue after the removal of the clay substance is determined, there is a means of calculating the felspar

present. Thus, multiply the alumina by 3·53, and, on the above assumption, the product will be the silica present in the felspar. All the other constituents of the felspar can be determined by analysis of the residue, and thus the weight of felspar is found. Suppose, for example, the alumina found weighed 0·014 gram, and the potash 0·013 gram, along with small amounts of lime, magnesia, etc. The weight of felspar would be—

$$\begin{array}{rl} & 0{\cdot}014 \text{ alumina} \\ 0{\cdot}014 \times 3{\cdot}53 = & 0{\cdot}0494 \text{ silica} \\ & 0{\cdot}013 \text{ potash} \\ \hline & 0{\cdot}0764 \text{ gram felspar} \end{array}$$

Subtracting the felspar thus calculated from the weight of the residue, the remainder is taken as quartz. In this way the clay is separated into its constituent minerals.

The information gained in this manner is very valuable and trustworthy, but it is much more so if the results of the ultimate analysis are available as well as those of the rational. From the two sets of figures, it is possible to calculate the percentage composition of the clay substance, which will powerfully affect the properties of the clays. In some instances the clay substance, by reason of paucity of fluxes, may be exceedingly refractory, while in other cases the clay substance may be, in fact, the main fusing constituent, being more easily fused even than felspar.

The composition of the clay substance is readily obtained. The rule is as follows: *Deduct the percentage amounts of each oxide found in the residue left after the removal of the clay substance from the amounts*

shown in the ultimate analysis. Add up the resulting remainders, and divide each individual amount by the sum of all of them, and multiply the quotients by 100. *The resulting numbers should total* 100, *and represent the percentage composition of the soluble dry substance.**

Thus, to calculate the composition of the clay substance in the following clay from details given :—

Ultimate analysis—

Silica	45·72
Alumina	38·56
Ferric oxide	0·61
Lime	0·24
Magnesia	0·22
Alkalies	2·11
Water	12·70
	100·16

Rational analysis—

Clay substance ... 97·32

$$\left.\begin{array}{ll}\text{Quartz} \;\ldots\;\ldots & 0{\cdot}32\\ \text{Felspar} \;\ldots\;\ldots & 0{\cdot}52\end{array}\right\} = \left\{\begin{array}{l}1{\cdot}94\ SiO_2\\ 0{\cdot}46\ Al_2O_3\\ 0{\cdot}44\ K_2O\end{array}\right.$$

Then—

		Clay substance.			Per cent.
Silica ...	45·72 − 1·94	= 43·78	÷ 97·32	× 100	= 44·98
Alumina ...	38·56 − 0·46	= 38·10	,,	,,	= 39·14
Ferric oxide	0·61	= 0·61	,,	,,	= 0·62
Lime ...	0·24	= 0·24	,,	,,	= 0·25
Magnesia...	0·22	= 0·22	,,	,,	= 0·22
Alkalies ...	2·11 − 0·44	= 1·67	,,	,,	= 1·71
Water ...	12·70	= 12·70	,,	,,	= 13·05
		97·32			99·97

* If the clay contains foreign soluble matter, such as carbonate of alkaline earths, ferric oxide, etc., these are first determined separately, and their amount deducted from the clay substance.

61. Calculate the rational analysis and the composition of the clay substances of the following clays from the analytical data given :—

	Ultimate analysis.			Analysis of residue.		
	(1)	(2)	(3)	(1)	(2)	(3)
Silica	63·44	55·79	45·45	35·22	16·40	0·98
Alumina	25·95	30·59	39·97	0·26	0·42	0·25
Ferric oxide	0·85	1·09	1·08	—	—	—
Lime	0·28	—	0·26	—	—	—
Magnesia	0·35	0·38	trace	—	—	—
Alkalies	1·62	3·28	1·19	0·17	0·36	0·14
Water and organic matter	7·12	9·27	12·33	—	—	—
	99·61	100·40	100·28	35·65	17·18	1·37

Ans.—

	SiO_2.	Al_2O_3.	Fe_2O_3.	CaO.	MgO.	$(NaK)_2O$.	Water, etc.
(1) Clay substance, 63·96; Quartz, 34·30; Felspar, 1·35 =	44·3	40·2	1·33	0·44	0·55	2·27	11·13
(2) Clay substance, 83·22; Quartz, 14·92; Felspar, 2·26 =	47·3	36·25	1·31	—	0·45	3·51	11·14
(3) Clay substance, 98·91; Quartz, 0·10; Felspar, 1·27 =	44·9	40·2	1·10	0·27	—	1·13	12·4

CHAPTER X.

THE APPLICATION OF THE RATIONAL METHOD OF CLAY ANALYSIS TO THE SYNTHESIS OF BODIES.

HAVING dealt in the preceding chapter with the method of rational analysis of clays and clayey mixtures, it remains to show how the results obtained may be usefully applied in practice.

It is necessary, however, to first indicate the limits to the application of the results of this method of analysis. As regards clay substance, the information yielded by the analysis of pottery bodies is incomplete. There is no indication of the origin of the clay substance, whether from china clays or ball clays, or from both. It is, however, important to know the kind of clay substance present, because that from china clays differs in physical properties very widely from that yielded by ball clays. Hence, if one is to synthesize an unknown pottery body from the results of rational analyses of the body and the clays to be used in its synthesis, the information at disposal is incomplete. In such a case, it is only by experiment that the amount of clay substance to be derived from the two clays respectively can be determined. All the data given is the total clay substance. Its apportionment between

the two clays is found by trial only. Still, even with this limitation, the results of the rational analysis give a very great assistance in the solution of the problem. The field of experiment is sharply and narrowly circumscribed, so that a satisfactory result is obtained with much less expenditure of time and labour. A classical example of the application, in this way, of the rational analysis is seen in the experiments made by Seger in his imitation of Japanese and other foreign porcelains and earthenwares. Full particulars of these experiments are given in Seger's "Collected Writings," vol. ii. (Scott, Greenwood & Co.).

Chemical differences between clay substance derived from various sources are ignored in the calculations necessary in such a synthesis as that just mentioned. Clay substance varies considerably in composition, and consequently its behaviour in pottery mixtures will vary. In many cases, however, the error likely to be introduced by this means will be but slight, for as a rule clays of the same type, and such as would be likely to be substituted for each other, possess clay substance of fairly definite composition. Thus all the Cornish china clays suitable for use in a white body have clay substance of about the same composition, and the same can be said of the ball clays of the south-west of England. Of course the clay substance from a red clay would differ widely from that occurring in a white ball clay; but then, a red clay would never be required as a substitute for the white one, and hence, so far as we are at present concerned, this difference of composition is of no moment.

In addition to the application of the data furnished by rational analysis to the synthesis of bodies, it is

capable of yielding great service to potters by enabling the substitution of clays for each other to be carried out with greater ease. Here, again, while the results of calculation are a great aid, they do not, in the absence of trial, constitute a certain guide. But, as in the previous case, the area of experiment is much diminished, and a result is more easily reached. It must, however, always be borne in mind that clay substance from china clay must not be displaced by clay substance from ball clay, and *vice versâ.* In the new body made from new clays there must be as much clay substance from china and ball clays respectively as there was in the old.

A. *The substitution of one clay for another in pottery body mixtures.*

It will often be necessary or advisable to adopt new brands of clay in the preparation of bodies. Unless the new clay is identical with the old in chemical and physical properties, its introduction will make other changes necessary in order that the final properties of the mixed body shall be unaltered. The character of the necessary changes in the recipe are best seen from a consideration of the rational composition of the old and the new clays; for evidently, if the new clay is richer in clay substance, say, than the old clay, a less amount of it must be used. A result of taking this diminished quantity is that the quartz and felspar now added to the body in the form of this particular clay are less than formerly, and therefore more must be added in the free state, or as stone and flint. If the new clay is poorer in clay substance, the reverse holds good.

Hence, to determine the changes in the recipe

necessary to enable a fresh brand of clay to be used, proceed as follows:—

Calculate from the rational composition of the clay in use and the quantity introduced into the body mixture, the amounts of clay substance, quartz, and felspar respectively. Then find the quantity of the new clay required to yield this amount of clay substance, and also the amounts of quartz and felspar which would accompany this clay substance. If more quartz and felspar are added in the latter clay, deduct the difference from the free flint and felspar; if less are added, then add the difference.

Example.—20 lbs. of a ball clay of following composition is used in an earthenware body:—

Clay substance, 87; quartz, 8; felspar, 5.

A new ball clay is to be used of composition—

Clay substance, 95; quartz, 2; felspar, 3.

What changes must be made in the recipe?

20 of original ball clay contain—

17·4 clay substance, 1·6 quartz, 1·0 felspar.

Then to obtain 17·4 lbs. clay substance we must use $17{\cdot}4 \times \frac{100}{95} = 18{\cdot}3$ lbs. of new clay, which will contain—

$$2 \times \frac{18{\cdot}3}{100} = 0{\cdot}36 \text{ lb. quartz}$$

$$\text{and } 3 \times \frac{18{\cdot}3}{100} = 0{\cdot}55 \text{ lb. felspar}$$

There is thus a deficiency of $1{\cdot}6 - 0{\cdot}36 = 1{\cdot}24$ lbs. quartz, and $1{\cdot}0 - 0{\cdot}55 = 0{\cdot}45$ lb. felspar.

Therefore the recipe must be altered, so that we use 18·3 lbs. new clay, and an addition of 1·24 lbs. quartz (flint), and 0·45 lb. felspar to the amount previously used.

62. For 30 lbs. of a china clay $\left[\begin{array}{lr}\text{clay substance,} & 96\\ \text{quartz,} & 2\\ \text{felspar,} & 2\end{array}\right]$ substitute one of composition $\left[\begin{array}{lr}\text{clay substance,} & 89\\ \text{quartz,} & 8\\ \text{felspar,} & 3\end{array}\right]$. Calculate necessary alterations in recipe.

Ans. 32·4 china clay (new), with 1·99 less quartz, 0·37 less felspar.

63. For 75 lbs. of a ball clay $\left[\begin{array}{l}\text{86 clay substance}\\ \text{10 quartz}\\ \text{4 felspar}\end{array}\right]$ substitute one having $\left[\begin{array}{lr}\text{clay substance,} & 95\\ \text{quartz,} & 3\\ \text{felspar,} & 2\end{array}\right]$.

Ans. 67·9 lbs. clay, with an addition of 5·5 quartz and 1·64 felspar.

64. A body contains—

40 ball clay $\left[\begin{array}{l}\text{86 clay substance}\\ \text{10 quartz}\\ \text{4 felspar}\end{array}\right]$

25 china clay $\left[\begin{array}{l}\text{91 clay substance}\\ \text{5 quartz}\\ \text{4 felspar}\end{array}\right]$

25 flint (pure silica)

5 felspar (pure)

Substitute a ball clay $\left[\begin{array}{l}\text{93 clay substance}\\ \text{1 quartz}\\ \text{6 felspar}\end{array}\right]$ and a china clay $\left[\begin{array}{l}\text{98 clay substance}\\ \text{1·5 quartz}\\ \text{0·5 felspar}\end{array}\right]$, and calculate the new recipe.

Ans. 37 ball clay, 23·2 china clay, 29·53 flint, 5·26 felspar.

65. In the body of the preceding question calculate the recipe if Cornish stone is used as the source of felspar, the stone consisting essentially of—

Clay substance ...	50	per cent.
Quartz	30	,,
Felspar	20	,,
	100	

Ans. 40 ball clay, 12·5 china clay, 17·5 quartz, 25 stone.

B. There is less certainty, in the absence of experiment, when one endeavours *to synthesize a body of known rational analysis from given materials,* because there is no indication as to the proportion of clay substance derived from the china and the ball clays respectively. In such cases assumed proportions must be taken, and trial must be made to determine which is best suited to the particular case.

Example.—It is required to synthesize the body –

Clay substance	67
Quartz	25
Felspar	8
	100

using china clay [95 clay substance, 3 quartz, 2 felspar], ball clay [84 clay substance, 16 quartz] pure flint, and felspar, assuming one-third of the clay substance is derived from china clay.

China clay required $= (\frac{1}{3} \text{ of } 67)\frac{100}{95} = 23{\cdot}5$ china clay containing 22·3 clay substance, 0·7 quartz, 0·5 felspar.

Ball clay required $= (\frac{2}{3} \text{ of } 67)\frac{100}{84} = 53{\cdot}2$ ball clay containing 44·7 clay substance, 8·5 quartz.

Total quartz added in the clays = 0·7 + 8·5 = 9·2
which leaves 25 − 9·2 = **15·8** flint to be used
Total felspar in the clays used = 0·5
which leaves 8 − 0·5 = **7·5** felspar to be added

Hence recipe becomes—

23·5 china clay
53·2 ball clay
15·8 flint
7·5 felspar

100·0

66. Put together a body to imitate the following :—

Clay substance ...	53·6
Quartz	36·7
Felspar	9·7
	100·0

using the raw materials of the last example, and making the same assumption.

Ans. 18·8 china clay, 42·5 ball clay, 29·36 quartz or flint, 9·34 felspar.

67. In Question 66, what would be the recipe if Cornish stone was used instead of felspar, the stone to be the same as in 65, and its clay substance to be considered as if obtained from china clay ; half of clay substance to come from ball clay ?

Ans. China clay, 2·7 ; ball clay, 31·9 ; Cornish stone, 48·5 ; flint, 17·0.

68. A bone china body shows on analysis—

45	per cent.	phosphate of lime
35	,,	clay substance
9	,,	felspar
11	,,	flint
100		

Put together a recipe using china clay of Example 66, stone of composition—

35 clay substance
35 quartz
30 felspar
———
100

pure flint if necessary, and pure phosphate of lime.

Ans. 45 phosphate of lime, 30 stone, 25·8 china clay.

THE END.

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